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THE
COMSTOCK LODE
ITS
FORMATION AND HISTORY

BY

JOHN A. CHURCH E.M. Ph.D.

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THE COMSTOCK LODE

ITS

FORMATION AND HISTORY

BY

JOHN A. CHURCH E.M. PH.D.

MEMBER OF THE AMERICAN INSTITUTE OF MINING ENGINEERS

MINING ENGINEER

ILLUSTRATED BY SIX PLATES AND THIRTEEN FIGURES

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John A. Gray, Agt.

PREFACE.

In undertaking the task of studying the Comstock Lode, I determined to derive the facts as much as possible from underground survey, believing that the two or three hundred rock sections which are afforded by the mining operations would be a more trustworthy source of information than any work done upon the shingle-covered surface. This volume therefore contains the result of studies which have been made from the standpoint of the miner rather than from that of the stratigraphical geologist, and the lessons derived from mining experience have received especial emphasis.

The present work covers but one part of the great problem which the Comstock region offers to the mining engineer. Deep mining, to be carried to the lowest limits possible, with its attendant questions of engineering, labor under extraordinary conditions of temperature, and ventilation, is only alluded to and not discussed. The equally important field of metallurgy has not been even touched upon. The omission of these things has brought into the work deficiencies against which it was vain to struggle. It is but a fragment taken from surroundings which are necessary to it.

My examination was made in connection with the United States Surveys west of the 100th meridian, and I am indebted to Brigadier and Brevet Major-General A. A. Humphreys, late Chief of Engineers, U. S. A., for permission to use the notes accumulated while in the Government service. The greater portion of the book was originally prepared as a report to the chief of the surveys. That portion was subsequently presented as a doctoral dissertation to the Trustees of Columbia College, New York.

I desire also to acknowledge the unvarying courtesy with which I was received by the gentlemen who have charge of the mines. To Mr. James G. Fair, then Superintendent of the Consolidated Virginia and California, and to Mr. W. H. Patton, then his assistant, and now his successor in the same office, to Mr. I. L. Requa, Superintendent of the Chollar Potosi, Mr. E. A. Schultze, Superintendent of the Bullion, Captain S. C. Curtis, Superintendent of the Justice, Captain T. G. Taylor, Superintendent of the Yellow Jacket, and Mr. Charles Forman, Superintendent of the Overman and Caledonia, I owe especial indebtedness for the unwearied kindness with which they responded to frequent calls for information and advice.

On this account I am indebted above all to the firm of Messrs. James & Wrinkle, surveyors to most of the mines, who freely extended the privileges of their office. Messrs. Hoffman & Craven, surveyors, were equally ready with assistance.

Messrs. W. B. Shepperd, of the Utah, M. G. Gillette, of the Savage, Philip Deidesheimer, of the Hale & Norcross, S. F. Jones, Superintendent, and Mr. Balch, foreman of the Crown Point, and Mr. Henry Bawden, now of the Julia, have all rendered me frequent and substantial aid. Mr. J. E. Gignoux, C.E., kindly undertook an examination of the Bullion which I was unable to make personally. Since my departure from the field, I have received important additions to the records of underground temperature from Captain Taylor and Mr. James, successive superintendents of the Yellow Jacket.

JOHN A. CHURCH.

115 Broadway, New York,
September 3, 1879.

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CHAPTER I.

THE COMSTOCK MINES.

It is fitting that a work on the structure of the Comstock Lode should be introduced by a description of the method employed in mining upon it. The known limits of the lode cover a space of 22,546 feet, in a nearly due north and south direction (magnetic). At the time the existing mine maps were laid out, the variation of the needle in that locality was 16½ degrees east. The northern half of the lode has a direction a little more to the east than the magnetic meridian, and the southern half a strike which again is slightly more to the east than its neighbor. Great irregularities in the course occur locally, the strike varying in fact from north-east to north-west within short distances. Still the mean direction of the lode is almost coincident with the line of magnetic north.

Upon this extensive seat of metalliferous deposition, the following mines have been opened, the list beginning at the northern end, and being divided into the Virginia, Gold Hill, and American Flat groups in accordance with the geological separation of the ore bodies. The names given these divisions are those of the towns which have been built upon them, and which rank in population in the order here given:

VIRGINIA GROUP.

	Length of Claim.	
Utah	1,000	feet.
Sierra Nevada	3,550	"
*Union Consolidated	575	"
*Mexican	600	"
Ophir	675	"
California	600	"
Consolidated Virginia	710	"
*Best & Belcher	540	"
Gould & Curry	612¼	"
Savage	$771\frac{2}{12}$	"
Hale & Norcross	400	"
Chollar	700	"
Potosi	700	"
Bullion	$943\frac{7}{10}$	"
*Exchequer	400	"
*Alpha	306	"
Imperial Consolidated	466	"
	13,549⅛	feet.

GOLD HILL GROUP.

	Length of Claim.	
*Challenge	90	feet.
*Confidence	130	"
Yellow Jacket	953¾	"
*Kentuck	$93\frac{11}{12}$	"
Crown Point	$541\frac{7}{12}$	"
Belcher	1,040	"
*Segregated Belcher	160	"
Overman	1,200	"
Caledonia	2,188	"
	6,397¼	feet.

AMERICAN FLAT GROUP.

	Length of Claim.	
Maryland	900	feet.
Baltimore Consolidated	1,200	"
American Flat	500	"
	2,600	feet.

* Worked through the shaft of a neighboring mine.

The mines above mentioned are followed by a number of others which from their position may have good reason to place themselves among the acknowledged mines of the Comstock Lode. None of them have produced ore, and only the southernmost, the Rock Island, has been worked to a considerable depth. No mining connection has been established between them and the known mines of the lode, and they are omitted from this list on account of their doubtful position. The three series of mines occupy a total length on the lode of 22,546 feet, as follows:

In the Virginia Group	17 mines.	13,549 feet.
In the Gold Hill Group	9 "	6,397 "
In the American Flat Group	3 "	2,600 "
	29 mines.	22,546 feet.

The length of the claims now included in the lode is more than one thousand feet greater than it was in 1866, the additions having been made on the extreme southern end in the American Flat district. The division of the lode among the mining companies also is not now what it was when the table quoted by Mr. Hague ("Survey of the Fortieth Parallel," Vol. III., p. 99) was compiled by Mr. R. H. Stretch, State Mineralogist of Nevada. That contained the names of forty-six claims, many of which were less than a hundred feet long. Several of these have been consolidated within late years, and one company, the Chollar-Potosi, has divided its ground between two companies, the Chollar and the Potosi. A practical consolidation has been accomplished by working two or more mines through one shaft. Thus the Union, Mexican, and Ophir are all worked through the Ophir shaft; the Best and Belcher is managed by the Gould and Curry officers, and the Imperial and Empire shaft is a point from which the Exchequer, Alpha, Imperial, Challenge Consolidated, and Confidence claims, covering 1392 feet of ground, are all explored. The Kentuck is worked through the Crown Point shaft, and the Segregated Belcher through the Belcher.

The number of working shafts distributed along the length of the lode in 1877 was twenty; to which must be added the air-shaft of the Belcher. Nine mines had no shaft, and some of them were among those of the first importance. This consolidation of interests is a favorite method of reducing the cost of exploration while the mine is in barren ground, and it can be and frequently is abandoned as soon as ore is reached. The great and increasing depth of the mines is no bar to this method of conducting the search for ore, because the energetic methods of mining practised on the Comstock allow the sinking of a deep shaft with extraordinary rapidity if the discovery of ore makes it advisable.

Mining began in the Comstock region in 1850, when gold was found by some Mormon emigrants in Gold Cañon, which leads from the immediate locality of the lode to the Carson River. The discovery was made near the Carson, and the work was confined to surface diggings. As these were pursued from one point to another, the Cañon was ascended until, in 1859, Gold Hill at the head of the Cañon was reached, and surface claims were staked out close to and probably including, the croppings of the great ledge. During the same period Six-Mile Cañon, which runs from the northern part of the Comstock to the Carson, as Gold Cañon runs from the central part, was worked, and in the same year, 1859, the Comstock Lode was discovered by a pit sunk for a water-hole. This was on the ground of the Ophir mine. Milling the ore began in October of the same year; but progress was slow, and the amount of bullion taken out in 1860 is estimated at only $100,000.

Since then the Comstock has become the greatest gold and silver mine in active operation in the world. It is extremely difficult to ascertain its true yield in the nineteen years of its history, and estimates vary from $300,000,000 to $350,000,000. During the earlier years very little effort was made to give accuracy to the statistics, and even the fuller data now obtainable must be regarded as a minimum, because they represent only that portion of the product which is extracted in the interest of the mine owners. In addition to this there are the battery slimes and the tailings, which are the property of the mills, and from which a large amount of bullion has been obtained.

In the following table the annual product is given from the best sources at command. For the most part it covers only that portion of the product which is accounted for to the mine stockholders; but it includes also about $6,500,000 obtained from tailings and from mines that are not on the Comstock, though in its immediate neighborhood. This addition probably compensates nearly for the omissions due to imperfect records, and the benefit to stockholders from the Comstock lode has probably been not far from $290,000,000.

	Gold.	Silver.	Gold and Silver.
1860*		$100,000	
1861*		2,000,000	
1862*		6,000,000	
1863*		12,400,000	
1864*		16,000,000	
1865*		16,000,000	
1866*		11,739,100	
1867*		13,738,618	
1868*		8,479,769	
1869*		7,405,578	
1870†		8,603,175	
Unclassified			$102,466,240
1871‡	$4,077,027	$6,230,587	
1872†	6,310,035	6,611,943	
1873‡	10,493,796	11,037,023	
1874‡	12,579,825	11,881,000	
1875‡	11,739,873	14,492,350	
1876‡	18,002,906	20,570,078	
1877§	16,130,996	17,760,702	
1878§	9,357,040	9,694,940	
	$88,691,498	$98,278,623	
Total			186,970,121
1877‖ Unclassified		$901,790	
1878‖ "		824,054	
			1,725,844
			$291,162,205
From mines in the Comstock region but not on the Comstock Lode, 1877 and 1878‖			$2,635,042

How much these figures should be increased to account for the bullion extracted from battery slimes and tailings, it is impossible to estimate with accuracy; but if an allowance of $5 per ton of ore is made on these two items, the above sum total would be increased by $32,500,000, and the entire product of the lode would be placed above $320,000,000.

The quantity of ore extracted is even more doubtful than its value, for no record of it was kept in the earlier years. It consists of two general classes, the rich ore, obtained when the mines are in bonanza, and the low-grade ore, which is worked during the intermediate periods of comparative barrenness. The former ranges usually between $40 and $108 returned to the stockholders, and the latter between $20 and $35. A good authority on this subject estimates the average value of Comstock ore in the past at $45 per ton of 2000 pounds, and this includes only the return to the companies. At this rate the above total of $291,161,205 represents about 6,500,000 tons of ore. To this must be added from two to ten per cent for slimes, which vary quite as much in value. In the early years of this region, the slimes and tailings were not always worked over, and that was also for some of the mines the period of richest yield. Taking all these circumstances together, it is probable that the allowance above made of $5 per ton of ore mined would cover the amount actually extracted from the slimes and tailings. It is very much in excess of the quantities reported to the Controller of Nevada for taxation.

---

* From J. D. Hague's Report on Mining Industry of the Fortieth Parallel, 1870.

† From Report of the U. S. Commissioner of Mining Statistics, 1871, corrected by data received from some mines.

‡ From Report of the U. S. Monetary Commission, 1877.

§ Reported by the mining companies with minor amounts taken from the Tax List.

‖ From State Tax List of Nevada.

The quantity of precious metals which has been allowed to run off with the exhausted tailings is unknown; but $40,000,000 is probably a minimum estimate for this item. Estimates of this kind are necessarily inexact.

Summing up these estimates, we have for the gross contents of the lode as worked up to the end of 1878:

	Per Ton.	Total.
Ore extracted		6,500,000 tons.
Bullion from the ore	$44.80	$291,161,205
Bullion from tailings and slimes	5.00	32,500,000
Lost in tailings	6.20	40,300,000
Total estimated assay value of ore		$363,961,205

If the percentage yield in the mills were accurately known, it would of course be possible to determine the value of the ore from their returns. But this yield has varied constantly, increasing with the improvement in machinery and practice from sixty-five per cent to seventy-two per cent. Seventy per cent is probably a somewhat high average, and adding three per cent for the amount extracted from tailings, which is also slightly in excess of the reported amount, we have a total yield of 73 per cent from the ore. Therefore the $291,000,000 which has been obtained from the lode represents a mass of ore containing a little less than $399,000,000 worth of silver and gold. Adding to this sum $9,000,000 for the value of the slimes, or a little more than three per cent, we obtain a grand total of $408,000,000 for the original contents of the ore taken from the Comstock mines in twenty years, ending with the year 1878. These two methods of computation therefore give results that differ by no less than forty-five million dollars.

Most of the bullion yield of the lode has been obtained from sixteen ore bodies or "bonanzas," and from low-grade ore which most of the mines continue to extract in large quantities after the rich quartz is exhausted. This is drawn from the same masses of quartz that furnish the rich ore, but is left in the mine until that has been removed. The bonanzas which have been found are as follows, beginning at the north end of the lode:

One in Sierra Nevada.
Two in Ophir.
One in Consolidated Virginia and California.
One in Gould and Curry and Savage.
One in Hale and Norcross.
Two in Chollar-Potosi.
One in the Imperial and adjacent mines.
One in Yellow Jacket.
One in Yellow Jacket, Kentuck, and Crown Point.
One in Crown Point and Belcher.
One in Belcher.
One in Segregated Belcher.
One in Overman.
One in Caledonia.

The number of these bodies is variously given by authorities, the doubt not resting upon denial of reported ore discoveries, but being caused by the difficulty of distinguishing bonanzas which are enclosed in the same mass of quartz, and only separated by low-grade ore which may be mined out afterward. The subject is not important; and no pains have been taken to form a decided opinion upon it. The Justice lode, lying near and opposite the southern end of the Comstock, has also produced one large ore body.

The great difference in the importance of the bonanzas is indicated by the fact that one of them, the last found and lying in Consolidated Virginia, California and Ophir ground, has produced no less than thirty-seven per cent of the whole product of the lode, or $108,861,230. It is now too late to attempt an accurate summary of the interesting facts connected with these remarkable collections of ore. The published records have always been of doubtful value, and the fire which destroyed so many mine offices in Virginia, in 1875, swept away nearly all the original notes and maps which could supply means for their correction. The following table is therefore given merely as an approximation to the truth. It was compiled by the San Francisco *Chronicle* in August 1877, and its statistics are brought down to June 30th of that year. In some respects it is obviously incorrect. It gives the dimensions of the "great bonanzas" as 500 feet high, 700 feet long, and 90 feet wide; and every one of these figures could be successfully disputed as being too small. But a mass of that size would yield 31,500,000 cubic feet of quartz, which at thirteen cubic feet to the ton would weigh 2,423,000 tons; a quantity which is nearly twice as much as this ore body has supplied. Doubtless the other dimensions shown are equally inaccurate. Nevertheless the table may give to persons unaccustomed to mining some idea of the scale upon which the metalliferous depositions of the Comstock lode have been made. It is copied with no change except the insertion of the true yield to date from the California and Consolidated Virginia mines. The sum total, it will be observed, does not agree with that given above, a fact which illustrates the conflict of authorities on the question of yield; but is also partly accounted for by the yield from low-grade ore which is not included. The number of bonanzas named in this table is twenty, or four more than I have accounted for. The discrepancy is due to the fact that the *Chronicle* tabulates the returns from *mines* rather than from bonanzas, and one of the latter may stretch through two or three of the former.

BONANZA.	Date of Discovery.	Position.	Depth.	Length.	Width.	Tons.	Average Yield.	Bullion.
Ophir, No. 1	1859	Surface.	200	200	40	109,166	$48 00	$5,210,000
Gould & Curry Savage	1860	Surface.	400	900	30	777,783	39 70	30,881,307
Gold Hill	1863	Surface.	450	1000	30	1,037,412	25 39	26,340,762
Yellow Jacket Kentuck Crown Point	1864	100 feet.	350	500	35	418,051	32 02	13,389,068
Belcher	1864	Surface.	150	200	30	55,288	34 39	1,901,117
Chollar-Potosi	1865	Surface.	300	500	50	553,958	25 39	13,985,415
Overman	1866	Surface.	200	250	30	110,669	14 26	1,578,388
Seg. Belcher	1866	Surface.	80	50	20	4,961	20 49	101,453
Caledonia	1866	Surface.	100	100	25	16,613	12 89	212,761
Hale & Norcross	1866	400 feet.	350	350	35	313,270	24 97	7,822,233
Sierra Nevada	1868		200	300	40	111,497	7 89	883,108
Crown Point Belcher	1871	900 feet.	500	600	60	1,374,528	42 40	58,110,240
Consol. Virginia California	1873	1100 feet.	500	700	90	1,090,360	93 55	104,007,653
Ophir, No. 2	1874	1300 feet.	300	300	30	264,000	20 70	5,548,055
Justice	1874	200 feet.	500	400	10	112,964	21 38	2,395,974
	Totals					6,350,520	42 89	272,367,624

The proportion of silver and gold in the ore, is another point which suffers considerable obscurity from the want of accurate book-keeping, though it has lately been the subject of careful calculation. It varies in different ore bodies and in different parts of the same bonanza. In the Crown Point and Belcher, the Belcher, or southern end, was richer in gold than the other half of the mass. In the Consolidated Virginia & California, the California or northern end had the larger proportion of gold. In the latter case the ore bodies were absolutely distinct and occupied different quartz masses which were nowhere united together, though closely adjoining. The Consolidated Virginia had produced up to December 31st, 1878, 26,141,851$\frac{8}{10}$ ounces, or 1101 tons, 861 pounds of bullion, and the California 16,900,770$\frac{7}{10}$ ounces, or 615 tons, 524 pounds. The California bullion was worth $2.56 per ounce, and the Consolidated Virginia $2.246.

The profit and loss account of the mines is probably quite as difficult to arrive at as the dimensions and yield of the bonanzas. All the facts which have been attainable are shown in the following table which relates to those companies that were in existence April 1st, 1879, and gives an account of their capital stock, dividends, and assessments, since the date of their incorporation.

NAME OF MINE.	Length of Claim.	Shares of Stock. Number.	Value per Share.	Capital Stock.	Total Assessments.	Date of last Assessment.	Total Dividends.	Date of last Dividend.	Date of Incorporation.
VIRGINIA GROUP.	Feet.								
1. Utah	1,000	20,000	$100	$2,000,000	$780,000	Feb., 1879.	None	....	Ap. 9., 1872.
2. Sierra Nevada	3,550	100,000	100	10,000,000	2,550,000	April, 1879.	$102,500	Jan. 16, '71.	....
3. Union Consolid'd.	575	100,000	100	10,000,000	460,000	April, 1879.	None.	....	Jan. 23, '75.
4. Mexican	600	100,800	100	10,080,000	221,760	May 15, '78.	None.	....	1874.
5. Ophir	675	100,800	100	10,080,000	2,340,744	Sept. 10, '78.	1,394,400	Mar. 7, '64.	....
6. California	600	540,000	100	54,000,000	None.	....	30,240,000	Jan., 1879.	Dec. 31, '73.
7. Consol. Virginia	710	540,000	100	54,000,000	474,600	June, 1873.	41,310,000	April, 1879.	June 7, '67.
8. Best & Belcher	540	100,800	100	10,080,000	438,592	Ap. 16, 1878.	None.	....	....
9. Gould & Curry	612¼	108,000	100	10,080,000	2,945,600	March, 1879.	3,826,800	Oct., 1870.	June, 27, '60.
10. Savage	771½	112,000	100	11,200,000	4,196,000	Feb., 1879.	4,460,000	June, 1869.	Oct. 14, '62.
11. Hale & Norcross	400	112,000	100	11,200,000	3,026,000	March, 1879.	1,598,000	April, 1871.	Mar. 19, '60.
12. Chollar	700	112,000	100	11,200,000	1,750,000	Sept., 1878.	3,080,000	Feb., 1872.	April, 1865.
13. Potosi	700	112,000	100	11,200,000	None.	....	....	....	....
14. Bullion	943¾	100,000	100	10,000,000	2,802,000	Jan. 22, '78.	None.	....	....
15. Exchequer	400	100,000	100	10,000,000	380,000	Jan. 17, '78.	None.	....	....
16. Alpha	466	30,000	100	3,000,000	240,000	Mar. 21, '78.	None.	....	....
17. Imperial Consol.	468	500,000	100	50,000,000	875,000	Feb., 1879.	None.	....	Ap. 13, '76.
Total	13,711¼	2,888,400	....	$288,840,000	$23,480,296	....	$86,011,700	....	....
GOLD HILL GROUP.									
18. Challenge Consol.	90	50,000	$100	$5,000,000	$10,000	Nov., 1878.	None.	....	Nov., 1873.
19. Confidence	130	24,960	100	2,496,000	256,320	Ap. 10, '78.	$78,000	May, 1865.	Aug. 11, '65.
20. Yellow Jacket	953¾	120,000	100	12,000,000	3,912,000	Jan., 1879	2,184,000	Aug., 1871.	Feb. 16, '63.
21. Kentuck	94	30,000	100	3,000,000	300,000	Aug. 7, '78.	1,252,000	Mar. 10, '70	Aug. 22, '65.
22. Crown Point	541½	100,000	100	10,000,000	2,053,370	Dec., 1878.	11,898,000	Jan., 1875.	Feb. 8, '61.
23. Belcher	1,040	104,000	100	10,400,000	1,592,400	Ap. 14, '79	15,397,200	Ap. 10, '76.	Nov. 2, '68.
24. Segrega'd Belcher	160	6,400	300	1,920,000	244,800	April, 1876.	None.	....	July 18, '65.
25. Overman	1,200	38,400	100	3,840,000	3,066,800	Jan., 1879.	None.	....	April, 1865.
26. Caledonia	2,188	100,000	100	10,000,000	1,645,000	Ap. 11, '79.	None.	....	May 2, 1871.
Total	6,397¼	573,760	......	$58,656,000	$13,080,690	....	$30,809,200	....	....
AMER. FLAT GROUP.									
27. Maryland	900	54,000	$100	$5,400,000	$54,000	May 9, '77.	None.	....	March, 1875.
28. Baltimore Consol.	1,050	84,000	100	8,400,000	936,000	Ap. 30, '78.	None.	....	July 3, 1872.
29. American Flat	500	30,000	100	3,000,000	172,500	May 18, '77.	None.	....	April, 1872.
Total	2,450	168,000	....	16,800,000	1,162,500	....	....	....	....

Summarized, the account stands as follows:

Number of Companies	29
Shares of Stock	3,630,160
Par Value	$364,296,000
Total Dividends	$116,820,900
Total Assessments	$37,723,886
Dividends less Assessments	$79,097,014

A large part of this assessment account has accrued during the last four years, which has been a period remarkable for the continuance of barren ground in all but five of the mines. The financial consequences of this misfortune have been increased by the depth of the workings, the flooding of two mines in the most favored part of the lode, the construction of new pumps of the heaviest and most expensive pattern, and the sinking of several new shafts designed to strike the lode at still greater depths. From all these causes combined, the assessments in Storey County in 1878 amounted to $8,561,600. This sum includes the levies of a large number of mines not on the Comstock lode, but the amount to be deducted on their account would be only a small portion of the whole.

In the third volume of Mr. Clarence King's report on the Fortieth Parallel Survey, Mr. James D. Hague, of San Francisco, has given a very thorough description of the methods of mining and the machines employed on the Comstock. That admirable treatise is still a trustworthy guide to the main features of the work and also to many details, most of the recent changes consisting in expansions of the former methods. In fact the plan followed, necessitated by the nature of the ground, has been quite uniform since the true eastward inclination of the lode was discovered. Since that time the works have differed more in magnitude than in plan. No attempt will be made here to repeat the information given by Mr. Hague, which will also be constantly referred to, and only a few of the additions to the mode of work will be described.

The Comstock is an example of an inclined deposit which is reached by shafts sunk through the hanging wall. The extreme rapidity with which the ground is worked out necessitates the frequent removal of these shafts in the direction of the inclination, and to avoid the sinking of so many new and expensive openings a system of combined vertical and inclined works has been introduced. On account of the moderate dip (30 to 60 degrees) of the lode it is not practicable to work a large number of levels from a vertical shaft, and no attempt is made to do this. As soon as the vertical or "straight" shaft reaches the lode its further construction is abandoned, and an incline is opened usually on or near the foot wall, but not conforming closely to it.

The vertical shafts have three or four compartments, disposed in a parallelogram, the only departure from this system being in the deep Forman shaft, which is L shaped. The inclines are mostly built for one track. From the incline a main drift is run north and south at those depths where it is desired to establish a level, and which are one hundred feet apart in promising ground, but may be three hundred feet apart in a barren zone. It is quite common now to maintain a practical uniformity in the position of these levels in neighboring mines, so that the main drift is frequently part of a gallery that may reach from one end of the actively worked ground to the other. While this is not true for every level, care is taken to make these connections at such distances as will secure good ventilation and the safety of the men in case of accident.

The deepening of the mines frequently amounts to 150 feet vertical in a year, and this corresponds to about an equal advance eastward, and about one half more excavation, following the inclination of the lode. For this reason the depth which can be worked from one point is rather rapidly exhausted, and in the nineteen years during which the Comstock has been worked upon there have been three principal bases of operation, as follows: 1. Surface works, consisting of "diggings," tunnels, and shallow shafts or inclines. 2. A line of deeper shafts, but not often exceeding 500 or 600 feet in depth. 3. The first line of deep shafts sunk through the hanging wall and reaching the lode at the depth of about one thousand feet or more. The surface works were mostly operated about 1860–'62, the line of shallow shafts about 1862–'65, and the first line of deep shafts was begun in 1864 by the construction of the Bonner shaft of the Gould & Curry. All the other mines followed this example, and the entire line from the Mexican to the Overman was probably complete by 1869 or '70. The average life of these shafts has been somewhat more than ten years, and the mines have deepened in this time from about the 700 to the 2000 level, and in some cases a greater depth. None of these data are exact, but they illustrate fairly the rapidity with which the resources of the lode are exhausted.

Within the past two or three years all the principal mines have attained the 2000-foot level, and many have passed several hundred feet beyond it. The depth named requires a hoisting cable about 2500 feet long, and for every foot further an increased length of cable amounting to a foot and a half is necessary. Such extreme lengths require very powerful machinery, and increase the chances of accident. A barren zone in the lode has also been reached where the ore deposits are not numerous enough to require the use of so many shafts, the intervals in the present line being often less than 1000 feet. A new line considerably removed to the east has therefore been occupied, and several shafts are now under construction, most of which are designed to supply the wants of two or three mines. The Union Consolidated mine, which has been hitherto worked through the Ophir shaft, now has a new shaft nearly 1500 feet further east. The Gould & Curry mine will have a new shaft, about 2300 feet east of the existing point of extraction. It will be known as the Osbiston shaft, from the superintendent of the mine. The Savage, Hale & Norcross, and Chollar Potosi mines have united in sinking a shaft known as the Requa shaft. It is about 3100 feet east of the lode croppings, and about 1700 feet east of the line occupied by the present shafts of those mines. South of this is the new Jacket or Taylor shaft, 2545 feet east of the present shaft. Finally, at the extreme southern end of the Gold Hill group of mines is located the important new Overman shaft, named after Mr. Forman, superintendent, the fourth in the history of that mine, and the deepest mining work which has been projected in America, if not in the world. It is no less than 3100 feet east of the present shaft. At what depth it will strike the lode cannot be positively foretold, but is expected to be 4500 feet in vertical depth. The Caledonia mine joins with the Overman in this great work.

Of these new undertakings, the Requa, Forman, and Osbiston shafts have four compartments each, and the Taylor has three. The Forman shaft is L-shaped, having three compartments 5 feet wide and 4½ feet, 4½ feet, and 6 feet long respectively. The pump shaft on the short arm is 6 by 7 feet.

The relative position of the various shafts is given in the following table, the distances being taken from the two datum points assumed in the construction of the maps accompanying this work. These are a north and south datum fixed in the Imperial between the Virginia group of mines (the shafts of which range northward from the assumed point) and the Gold Hill group, where the distances read southward from the zero line. The other datum is common to the whole lode, and is a magnetic north and south line drawn about 100 feet west of the Eldorado croppings of the Gould & Curry mine. In addition to these the altitude of the shaft mouth, referred to a common datum—"Point A" of Mr. King—is given.

SHAFTS OF THE VIRGINIA GROUP.	Depth below Point A.	Distance North from Datum.	Distance East from Datum.
	feet.	feet.	feet.
Sierra Nevada	362	10,283	2,422
Union Consolidated	(320)	......	(3,000)
Ophir	263	7,620	1,538
C. & C. (California and Consolidated Virginia)	353½	6,713	2,414
Consolidated Virginia	238	6,575	1,443
Gould & Curry (Bonner Shaft)	200	5,164	1,197
Gould & Curry (Osbiston Shaft)	(450)	......	(3,300)
Savage	213	4,252	1,418
Hale & Norcross	237	3,710	1,595
Chollar-Potosi	168	2,831	1,220
Requa Shaft	(260)	......	(3,100)
Bullion	371	1,485	345
Imperial	231	295	760

SHAFTS OF THE GOLD HILL GROUP.	Depth below Point A.	Distance South from Datum.	Distance East from Datum.
	feet.	feet.	feet.
Yellow Jacket, New Shaft	(340)	1.650	(3,128)
Yellow Jacket, "South Shaft"	433	1,092	578
Crown Point	469	1,400	437
Belcher, Air Shaft	....	......	......
Belcher, South Shaft	414	2,510	128
Overman	662	3,871	1,600
Overman-Caledonia, Forman Shaft	(360)	......	(6,000)
Caledonia	607	5,376	1,609

The numbers marked in brackets are merely approximate, and it should be noted that none of the distances given in this table were obtained by measurement on the ground, but from the map, and are therefore subject to small though unimportant errors. The position of the Utah shaft and of the shafts in the American Flat group of mines is not known to me, since those mines though mapped separately, have not been plotted on the great map of the lode, which covers only the productive ground of Virginia and Gold Hill. In the following table some additional facts are given:

Other Points in the Comstock Region.	Depth below Point A.	Distance North or South from Datum.	Distance East from Datum.
	feet.	feet	feet.
Julia Shaft	277	2,585	2,207
Ward Shaft	277	......	......
Justice Shaft	932	......	......
Sutro Tunnel, Mouth	1,858	......	......
Sutro Tunnel, connection with Savage Mine	(1,813)	......	......
Knickerbocker Shaft	518	......	......
Baltimore Consolidated Shaft	658	......	......
Rock Island Shaft	713	......	......

The depth at which the new shafts will strike the lode depends upon the local dip, which varies greatly ; but in general they will sink more than 2500 feet through the hanging wall and be on the average about twice the depth of the present vertical shafts.

Some of the existing shafts do not fit exactly into this general scheme. The Overman, for instance, and the Sierra Nevada tap the lode between 1300 and 2000 feet in depth ; but in general there is considerable regularity in the eastward progression of the line of works. A discovery of ore in depth would establish all the mines on the lode upon the new line.

Work upon the Comstock mines is unusually irregular, even for such irregular subjects of industrial operations as mines mostly are. The absence of a vein and the occurrence of large ore masses and perfectly barren ground in a succession that cannot be foretold, gives to mining in this lode the most extreme alternations of good and bad fortune. The ground in which lay the great bonanzas of the California and Consolidated Virginia mines yielded some ore above the 200 foot level, and then was practically barren down to the 1200 level. From the next four hundred feet of depth a million tons of very rich ore has been taken. Such vicissitudes necessarily induce irregularity in working, which is further increased by the differences which exist in the length of the various claims.

It is matter of course that the progressive increase in depth should be less when a great ore body is removed, than when works of exploration are carried on in a barren and unpromising part of the lode. But the extraordinary vigor of operations in these mines somewhat counteracts this cause of fluctuations. When ore is at hand in large quantities the extraction is pushed with such speed that a deposit containing $150,000,000 worth of metal may be mostly removed within four years from the time of discovery ; the whole work of laying out the levels and extracting the ore being done in this time. The Consolidated Virginia mine yielded 144,400 tons of ore in 1877, or 400 tons daily for 362 days ; and the California had probably about the same yield from the neighboring ground. With such energetic management it is not strange to find the mines deepening at the rate of 100 feet a year, even when in bonanza.

The New Jacket shaft, begun October 7th, 1876, was carried to the depth of 2250 feet in twenty-eight months, an average progress of 81½ feet per month. For some time the work was retarded by swelling ground ; but pumps were not required for the first half or two-thirds of the sinking, the water being bailed out with the ore-skip. The work was not pressed with unusual vigor but carried on as steadily as the ground permitted.

This rapid work is the result partly of high wages, admirable organization, and the lavish use of machinery. A large number of machine drills are in use, the Burleigh and Ingersoll being both highly praised. The administrative vigor which characterizes the management of these mines has made the employment of machinery for drilling a success wherever tried. The drifts are pushed forward at the rate of three to eight feet a day, and shafts at three to five feet. The higher rate is usually the result of machine-work ; but hand-work also produces results that would be considered extremely rapid, even for machinery elsewhere.

Rapid progress is obtained here, as it is in most mining works, by the use of heavy powder charges and high-grade explosives. Picking and gadding are not much encouraged when the ground will blast well. For softer ground, where these modes of breaking down are advisable, shallow holes, three or four inches in depth, are sometimes made over the face of the header, and cartridges about an inch long, called "gophers," without tamping, are exploded in them. In ground which has been shattered in this way, excellent progress can be made by picking.

Black powder is little used ; nearly all the work being done with the nitroglycerine compounds. Of these, Giant powder, Hercules powder, and Vulcanite have been introduced ; the first-named being the principal dependence. Electricity is not used for firing, a fuse being inserted into the exploder. At the Sutro Tunnel the electrical mode of ignition was in use, and caused some very serious explosions. In spite of all precautions, the use of the electric exploder was found to be dangerous in the dry air of Nevada.

The high rate of progress is partly due to favorable ground. All the rocks encountered in the mines blast well, and the details of the work in excavation show that the rapid advance is obtained without resort to those strenuous efforts which are necessary in some other places. Comparing the Comstock drifts with the railroad tunnels, which seem to be the only rivals to them in swiftness of execution, it is immediately evident that decided differences exist in the details of work. In the tunnels, drill-holes of eight to eleven feet deep are common ; but on the Comstock five feet is usually the maximum depth, even of machine-drill holes ; and more frequently they are thirty to forty inches deep. Hand-worked holes vary from ten to thirty inches. This comparative shallowness is an inevitable consequence of the narrow quarters in which the machines work.

All these details have come gradually into use, and though the mines have never enjoyed a common direction, the practice is essentially uniform throughout the district. While it is never safe to say that efficiency can go no further, it is probable that drilling and blasting are near their maximum of excellence in Comstock mining. These parts of the task involved in the extraction of subterranean rock have in fact reached a state of excellence that is much in advance of some other divisions of the labor. The removal of freshly blasted material is as slow here as it is in all single-track drifts, and greatly retards the progress. Probably one-half the time required for breaking down is spent in filling the rock into cars and running these to the shaft ; and any means for hastening this work would be a valuable addition to the mining methods of the Comstock.

The cars used are now always made of iron ; but the construction otherwise has not been changed from that which Mr. Hague described and illustrated. The load carried is still somewhat less than one ton, the large cars taking not more than 1800 or 1900 pounds.

The disposition made of the car-load varies with the position of the level. When this runs out from a vertical shaft, the car is pushed upon a cage and hoisted ; but when the level connects with the incline, the load is tipped into a shoot excavated over the incline. From this shoot the ore is loaded into the "giraffe," while the car returns for a new load, not leaving the level. This mode of extraction was barely introduced in Mr. Hague's day, but is now the prevalent one in the deep shafts. The name giraffe is given to the large car, holding twelve or fourteen tons, which runs in the incline.

The principal innovations which have been made in the machinery of the mines since Mr. Hague's description was published in 1871 are:

1. Introduction of compound pumping-engines, with the Davey differential valve gear, modified by Mr. W. H. Patton. 2. Introduction of a direct-acting hoisting-engine, and increase of hoisting-speed to 1100 feet per minute. 3. Invention of the "skeet" by Mr. I. L. Requa, Superintendent of the Chollar-Potosi mine. This name is given to a large skip or ore-bucket, the use of which replaces the cage and avoids the necessity of hoisting the cars. Holding 4½ tons, it will raise more than a cage with four decks, and very much diminishes the dead weight to be lifted. It is self-dumping. This apparatus has been placed in the Requa, Taylor and other shafts, and if it approves itself upon extended trial, it may have an important effect upon Comstock mining and play an excellent part in removing some of the difficulties of deep mining. 4. The use of galvanized iron air-pipes instead of the old red-wood boxes. Small as this detail is, no step can be taken in the management of ventilation in these mines without producing important results; and this has no doubt greatly improved the efficiency of the air supply.

These points of distinctively engineering features will not be further touched upon; but there are others which concern the physics of the lode that will be described. They relate to ventilation and water supply.

Ventilation is secured by a combination of natural and artificial means; but underground the latter is mostly employed. Some also employ forced air-currents from the surface; but the apparatus is entirely inadequate to the supply of the large quantities of air required in these hot mines. Root's blowers are most used, though the largest machine of this kind is of the Hawkins pattern. A Guibal suction-fan was placed at the mouth of the Gould & Curry adit; but the nearness of the adit to the surface effectually prevented useful results from it.

Brattices are sometimes found in main air-ways, and especially in the inclines; but the conditions of the ground are such that this mode of guiding air-currents is troublesome and costly in the vertical shafts. All the shafts on the lode lie in a hanging wall that has been undermined by extensive excavations, and even when this ground has settled to a firm condition, there is always local movement in the country rocks. The stratified condition and varied character of the material, the vast masses of soft clay or rock that decomposes, swells and flakes away under the action of the atmosphere, with which this ground is filled, makes every opening insecure. Pressure and crushing are simply questions of time in every shaft, and the mode of timbering which has come into use, is designed to meet these peculiar exigencies. It consists of heavy timber frame work, unfastened and held together entirely by the pressure it sustains. This timbering is the invention of Mr. Phillip Deidesheimer, now superintendent of the Hale & Norcross mine, and is fully described and figured by Mr. Hague. It allows considerable movement in the rock without losing its value as a safeguard, and this quality is so important that there is strong objection to placing stiff brattices, securely fastened, in the works. Air-currents from the surface, when forced, are therefore always sent down by pipes of galvanized sheet-iron eleven to twenty inches in diameter; and it is probably owing to these difficulties that the artificial ventilation of these mines is so unimportant. This remark does not apply to the local movement of air from one part of a mine to another. That is in use everywhere, and is accomplished by small engines which will be spoken of hereafter.

Even the natural ventilation of these mines is remarkably small considering the vast heating powers of the hot rock, and the fact that even in summer an addition of from twenty to thirty degrees is made to the temperature of the air passing through the mines, while in winter the difference is greatly increased. In nearly all cases a shaft is exclusively down-cast or up-cast, and the mines are divided into six down-cast and ten up-cast. In addition, the Gould & Curry had air-currents both ways in its shaft, and the Belcher has a special air-shaft for down-cast. On the 2d of July, 1877, the amount of air rising from eleven up-cast shafts (including the Gould & Curry), with its temperature, was as follows:

	Cubic Feet per Minute.	Temperature of Upcast.		Top of Shaft.
Utah	4,000	..	degrees	Fahr.
Sierra Nevada	7,700	76	"	"
C. & C.	21,600	84	"	"
Consolidated Virginia	48,750	89	"	"
Gould & Curry	12,000	..		
Savage	58,500	100	"	"
Chollar-Potosi	18,000	77	"	"
Bullion	10,080	89½	"	"
Imperial Consolidated	28,800	95	"	"
Belcher	52,200	89	"	"
Overman	27,000	93	"	"
Total cubic feet per minute	288,630			

This is probably to be considered as near a minimum quantity. A great difference is discernible in the ventilation of the mines on different days, due perhaps to the direction of the wind. This day (July 2d, 1877) was not a bad one, and the outside temperature, taken in the shaft-houses (and therefore in the shade) of those mines which were down-cast, averaged about 73 degrees F. from 10 A.M. to 4 P.M.

The supply of air may be taken at eleven and a quarter tons or 300,000 cubic feet per minute, as the old Chollar and Kentuck shafts, both up-cast, were inaccessible. Probably 10,000 feet of this quantity is supplied by the numerous air-compressing machines in use, and 30,000 feet by the blowers. The up-cast shafts had an aggregate section of about 750 square feet, the area of which was diminished by an unknown quantity due to the presence of the cages at various stages of their paths. The minimum average velocity was therefore 400 feet per minute. Considering the straight course and excellent condition of the air-passages, and the short paths of most of the currents, this result cannot be regarded as a very successful utilization of the great working powers of this extremely hot lode ; but the causes of the deficiency, aside from the small section of the drifts as compared with those of coal mines, are not understood.

The velocities actually observed (with a Byram anemometer) varied from 200 to 900 feet per minute, the lower rate being obtained in those mines which have unusually long air-ways. The Savage, Bullion, Imperial, and Overman gave a velocity of 550 feet to 590 feet ; the C. & C. 400 ; Consolidated Virginia, 620 ; and Belcher 900 feet per minute.

Though ventilation is the life of all mines, the air-current is an especially beneficent visitor in the Comstock works. Nevada has a dry climate, and its atmosphere must have very high powers of hygroscopic absorption, which are further increased by the elevation of temperature which the air experiences in the mines. All of this is utilized, and the up-cast current is so loaded with steam that it rises in a solid body of vapor thirty or forty feet above the shafts. The vaporization of this great amount of water must have a very marked effect in cooling down the drifts, aided as it is by the expansion of about 10,000 cubic feet per minute of air which has been compressed to one-fourth its usual volume, and the absorption of the heat which raises the whole current to a temperature of more than 90° F.

The unusual importance of the air-current in these mines is illustrated by the history of the 1850 level of the Bullion mine. This level was first opened from the Imperial shaft and attained a length of 1700 feet before any attempt to establish an air connection in the Bullion was made. The thermometer is reported to have ranged between 130° and 140° F., and work in the drift was extremely difficult and costly; but the State Mineralogist says that when a through current of air was established, the thermometer fell from 138° to 100° F. Here was an increase of thirty-eight degrees merely from the mode of working.

At the time the observations given here were made, there were about 2700 men working underground in the mines in Virginia & Gold Hill They worked in three "shifts" of eight hours each, and the allowance was therefore 300,000 cubic feet per minute to 900 men, or 330 cubic feet per man. This is very much in excess of the theoretical requirement, the amount required by law in the coal mines, where vast quantities of gas are discharged, not being above 100 cubic feet per man per minute. This quantity is itself a maximum designed to cover all possible contingencies, including the effective dilution of the coal gases. But the three times greater quantity which the Comstock mines receive is not sufficient to keep them cool nor to secure really comfortable conditions for work.

In another place it is shown that the heat of these rocks is probably due to the condensation of atmospheric water in the process of kaolinization, or transformation of the feldspathic rock to clay. By this action currents of gas, of which carbonic anhydride probably forms a principal part, are discharged, and take their way through the dry portions of the rock, conveying the heat produced to any opening by which they escape. It is probably to this agent in part that the nauseating effects which are sometimes felt even in the presence of a fair amount of ventilation are due. When the Sutro Tunnel reached the Savage works in July, 1878, and a current of air was established through the tunnel into the mine, and thence 1600 feet upward to the surface, the air from the tunnel was said to be "sickening," though men had been working in it, with fair ventilation, and without unusual inconvenience for years. In this case the more vigorous movement of the air seems to have swept out the gas accumulated in the irregularities of the tunnel walls, and several days passed before the purity of the current was restored.

The steaming atmosphere of the mines may contribute to the exhaustion which work in them induces; but whatever the causes, it is certain that the work is trying, and its severity is less dependent upon the temperature than upon deficient quantity of the air-current. This was constantly proved by leaving thermometers with the men who would not, without experimental proof, believe that the places which they sought for cooling off were sometimes hotter than those where they worked, and frequently had precisely the same temperature. It is true that an increase of a few degrees in the temperature of a drift will sometimes bring with it an exhaustion which is out of proportion to the heat change alone. This is explainable on the supposition that the increased heat is due to an unusual access of gas, and such places frequently become more comfortable after a few days. For this reason they are sometimes abandoned for a short time, "to cool off."

It was invariably observed that while the men wanted constant change of air, they did not enjoy too strong a draft. They would complain if the fan engine was run too fast. On one occasion this fact was proved to me by the foreman of a mine, who quietly opened the throttle of the fan engine enough to speed it a little above its usual rate, though not to an excessive degree. My impression was that the change would be an improvement, for the drift to which the pipe led was probably 500 feet long, and quite hot. But in a few minutes one of the men came to the station and turned the valve back, saying it was "cold!" In this case the air at the fan had a temperature of 88° F., at the end of the air pipe 108° F., and in the drift about midway of its length 112° F. The latter was probably about the temperature of the atmosphere in which the men worked.

These conditions which are due to the character of the ground in which the mines are excavated, are supplemented by the requirements of vein mining. Labor is performed in narrow quarters, only a small portion of the lode material being removed in the work of exploration. Long stretches have to be excavated before a connection with a distant air-shaft can be established and a special mode of ventilation must be employed to supply the men working in these *culs de sac*, which are particularly subject to the peculiar conditions of the locality, for the reason that they are continually advancing into fresh ground.

In these points which are removed from the line of the natural air-currents, ventilation is obtained by forced blast, and the machines which supply it are mostly placed below ground. They are ordinary upright engines of two to five horse power worked by compressed air at 60 pounds' pressure, supplied from the surface. Connected with each engine is a four-vane fan of simple construction, made in the shops of each company; and the air which these machines supply is taken to the end of the drift, or "header" by galvanized iron pipes eight or eleven inches in diameter. The engines are placed at some point in the main air-way, and take air of 75° to 95° F. temperature, the quantity being usually from 700 to 1000 cubic feet per minute to each fan. This may furnish three to seven men with air.

Contrary to the usual practice in mining, the air is supplied by pressure instead of exhaustion; and this feature of Comstock engineering, which seems to be a matter of criticism to those who are not initiated in the peculiar requirements of work in these mines, is really one of the points most essential to the comfort of the men. The air-pipe terminates within twenty feet of them, and the current of fresh air is directed immediately upon their half-naked bodies, assisting in the rapid removal of the streams of perspiration which pour from them in quantities sufficient to soak their garments, fill their shoes, and even moisten the rock under their feet. The men drink copiously of ice-water, which is supplied without stint, and an allowance of three gallons per man is probably a minimum estimate for eight hours' work. All this is removed through the vigorous action of the skin, and the main condition for comfort to the men seems to be the quick removal of that part of the perspiration which is vaporized. If this hangs about the person, or if the vaporization is insufficient, there is a sense of suffocation; and this may take place either with deficient ventilation or even in a fair current of air if it is humid. Heat which increases the capacity of air for absorbing aqueous vapor may be in this way favorable to comfortable working, a fact which explains the relief so constantly obtained in a current of warm air. Throughout the mines it was observed that the men did not seek coolness, but quantity of air, and probably quality also, that is, capacity for absorbing moisture.

For the latter reason, the air which is taken from a current having a temperature of 85° F., and is sent through a long pipe where it is heated to 100°, has its capacity for aqueous absorption increased so as to act with the highest efficiency when thrown upon the men. If the contrary method were used, and the air were drawn from the end of the drift through the pipe, as the managers are sometimes advised to do, the men would inevitably be put to great discomfort. Instead of a velocity of 1000 feet per minute, the air would not have a greater movement than 40 feet per minute, and in passing through the drift it would pick up all the deleterious gases and all the moisture in its path. It would have no force of projection upon the men, and the constant exchange of atmosphere which is now obtained in the header, would be lost. Without making radical and probably impracticable changes in the quantity of air supplied, there can be little doubt that the method of ventilation by exhaust fans would almost cause the closing of the mines.

Still, the day is approaching when the present means of ventilation may be found insufficient, and a change of plan be necessary. It is probable that an intelligent study of the conditions under which personal comfort is secured will establish methods of ventilation that will allow the triumphant accomplishment of mining at depths of four and five thousand feet, even in these extraordinary natural furnaces. In another chapter it is shown that the most active centres of the heat are small and often can be avoided in planning the drifts, or confined by tight lagging, devices which may permit mining in much hotter ground than that of the existing levels. As the heat of the rock increases, the temperature and capacity for aqueous absorption of the air-current also increases, and the latter advantage can perhaps be heightened by drawing the air-currents direct from the surface. Thus in addition to improvement from increased care in management, the evil of increasing rock temperatures tends to correct itself by making the cooling and sustaining effects of the forced ventilation more vigorous. Of course there may be a point where the air will be too hot for the lungs to receive without injury ; but the existing experience shows that a temperature of 123° and above this can be borne successfully, provided the action of the skin is properly maintained.

Pumping. The country rock which encloses the Comstock is divided into distinctively wet and dry portions, arranged in a series of alternations parallel with the lode. The dry ground is in large excess over the wet, and it is so dry that the usual seepage, which takes place in all rocks, is quite insignificant. It is most often solid, but fissured portions are met with. Fissuring and decomposition are, however, the distinctive characteristics of the wet ground which occupies comparatively narrow bands, two or three hundred feet being probably a maximum thickness. Their vertical extent and their length are probably very great, for they pour out immense volumes of water, and for several years it was supposed that there must be large chambers in the rocks holding water, so great was the quantity yielded by some of the "water bonanzas." No such chambers have ever been encountered in the extensive explorations in the country rock, and there is no doubt that the seat of the aqueous stores is the soft and fissured seams which are constantly met with.

The quantity of fluid which these shattered bands will hold is immense. Three years ago the Savage & Hale and Norcross mines were flooded by water, which entered on the 2200 foot level, and rose to about the 1750 level, flooding also the 2400 level which had been partly opened. The water therefore had a head of 450 feet, which must have been due entirely to hydrostatic pressure, and the freedom of movement within the seamy magazine is shown by the fact that here, as well as on other similar occasions, the miners had to fly for their lives, so rapid was the influx. New pumps, capable of throwing about 10,000,000 gallons per month to the surface, were immediately built for both mines, and have been working with great vigor ever since, but had not been able by the middle of December 1878 to reduce the water to a greater depth than 50 feet below the 2000 foot level, where it remained for several months longer. Great difficulties were experienced in the Savage by the breaking of the pump-rod, and it is not probable that the pumps of the two mines have averaged more than three quarters of their full working capacity. Still that ratio would give for thirty months 450,000,000 gallons, or 1,800,000 tons, estimating the gallon at 8 pounds. This represents the quantity of water supplied by about three hundred feet of head. Two hundred feet remain to be overcome, and what amount of the fluid this represents cannot be foretold. The reduction of the water level is by no means very rapid nor uniformly continuous, and it is not possible to say how much the fissured water-bearing seam extends below the 2200 level. The Sutro Tunnel, which has been carried through to the 1640 foot level of the Savage mine, offers an opportunity for reducing the lift of the pumps, and increasing their size.

The third anniversary of its appearance (March, 1879) found this flood in full possession of the two mines, and the height was near still the 2000 foot level. Considering the depth at which it lies, and the character of the mines it has overcome, this "water bonanza" may fairly take position among the historic floods which have defied the intelligence and determination of man.

The Sutro Tunnel offers another example of the immense quantities of water which the rocks of this region locally contain. The quantity flowing from it has of course increased steadily with its progress, and now appears to be about 1,250,000 gallons a day, the tunnel being 20,489 feet long. Whenever wet ground was encountered the flow increased, reaching its highest point in October, 1876, when it was 244 miner's inches, or more than 4,000,000 gallons daily. This great work of engineering offers the best evidence of the banded nature of the water reservoirs. They have been repeatedly cut and passed in the tunnel, and always found to be soft and shattered seams of rock, and never vacant spaces. The next two or three years of experience in the tunnel will have great interest from its bearing upon the important question of what amount of atmospheric water reaches the tunnel level yearly. At present it is impossible to say how much of the floods which enter the mines is due to constant supply, and how much to the exhaustion of stores accumulated in the rocks. Upon the Comstock the impression is common that the current supplies from the atmosphere are very small, and it is in fact an ordinary occurrence for almost overwhelming floods to dwindle away to insignificant streams ; but it is also true that some supplies are quite constant, as in the Ophir mine, which has pumped from its upper levels for years since they were worked out and abandoned, the lower levels meanwhile remaining remarkably dry.

It is noteworthy that while the country rocks contain these immense accumulations of water, the lode itself is tolerably free from them. Often it is quite dry, but sometimes contains a considerable amount of water, lying in the loose "sugar quartz" as in a sandstone bed. As a rule, these accumulations drain away rather rapidly, and are never so persistent as the great bodies from outside the lode. It is the country rock and not the lode that is distinctively the water-carrier, a fact which is probably due to the entrance of siliceous waters on the line of the lode, and the deposition of quartz in the crevices which elsewhere are free to store up water. It should be mentioned however, that a flow of water is looked upon as a favorable sign and promise of ore by the miners. Such indications of course depend upon position for their value, since floods of water have frequently been struck away from the lode, in points where there could be no sound expectation of ore. It is also possible that the value of water as a sign of ore, even within the just limits of the lode, has passed away as the mines have gained depth. In the upper portions the barren quartz was distinguished for its hardness and close structure, while the ore quartz was porous and loosely coherent. There was a well marked difference in the storing capacity of the two kinds of material, and water was no doubt often a true sign of the quartz that usually carried ore. But in the lower levels the strength of these distinctions is much diminished. Hard quartz is met with, but in proportion it is much diminished, and a flow of water in the lode is no longer a sign that a neighboring body of quartz is an ore carrier.

The liability to overwhelming floods of water compels the mines to maintain pumps of the largest size, even though no extraordinary amount of water is encountered for years. They are all Cornish pumps, and the underground arrangements are still in the main what they were when Mr. Hague figured them in 1870, with exception of the size, which has been increased. Above ground great changes have taken place. The old cog gearing has given way to direct action in all the new pumps except that of the Jacket. Compounding, and the Davey differential cut-off, with a modification by Mr. W. H. Patton, have been applied to all new constructions, and the Comstock now presents a line of powerful pumps constructed after the latest models. Beginning at the south end of the lode, we find the following new machines. The table also gives the number of strokes at which they were running in the autumn of 1877; but the maximum speed possible is about the same in all of them. This is lower on the Comstock than in cooler and drier mines. The difficulty of maintaining long pump-rods in a steaming atmosphere and over shifting rock surfaces, does not permit a higher speed than eight and a half strokes per minute.

	Pump.		Strokes per Minute.	Hours of Daily Run.
	Stroke.	Diameter.		
	feet.	inches.		
Overman	8	14	1⅛ (registered).	24
Belcher	8	14	3½ (registered).	24
Yellow Jacket	10	14	....	..
Requa Shaft	8	Two barrels, each 15 in.	....	..
Hale & Norcross	7½	13	6½ to 7½	24
Savage	7½	{ 14 in. vertical shaft. { 13 in. inclined "	6½ to 7½	24
Gould & Curry	7	14 & 12	4 to 4¼	24
C. & C. Shaft	7	12	7 to 8	24

Six of these pumps, together with the old ones, were in the summer and fall of 1877 raising 350,000 to 400,000 tons of water monthly. The efficiency of the new form of pumping-engine is shown by the record of the Hale & Norcross pump for eight months, from October 1st, 1876. This mine being flooded, the pump was worked continuously.

Total Strokes	2,046.938
Strokes per Minute, including stops	5.85
Stoppages	9 days, 16 hours, 48 minutes.
Strokes per Minute, excluding stops	6.119
Water pumped	84,436,192½ gallons.
Wood consumed	3,027 cords.
Cost	$41,721
Stroke of Pump (actual)	6 ft. 5 in.
Gallons per Stroke	41¼

The cost per gallon was not quite half a mill, 20.24 gallons costing one cent. The height of the lift varied as the water fell from a depth of 1670 feet to 1945 feet, the lowest point reached in this period. Probably the average lift was near 1800 feet.

From October 1st, 1876, to March 1879, or in twenty-nine months, this pump made 7,432,054 strokes, and raised 306,572,228 gallons, at a cost of 8649 cords of wood, valued at $10.50 per cord. The stoppages amounted to 903 hours, 44 minutes.

The Hale & Norcross, Savage and C. & C. pumps were working at their full capacity; the Belcher, Overman, and Gould & Curry pumps were working at reduced speeds; the Requa had no spear-rod, and the Jacket was not built in the fall of 1878. Three of the series were therefore run at their full capacity, three others at diminished speed, and two were idle. The total capacity of these new pumps may be taken at about twice the amount of water they were actually throwing at the time mentioned, or about 80,000,000 gallons, or 320,000 tons a month.

Of the old geared pumps there were six at work raising about one-third the water of the lode. This does not include either the number of pumps in idle mines or in those mines which, like the Julia, do not claim to be on the Comstock proper. The latter lie so near that lode as to drain the same rocks, and in any complete computation of drainage they should be accounted for.

The spear-rods are always of Oregon pine, and vary from 11 to 14 inches in diameter. The extreme variation in quantity of water to be raised is not usually met by especial arrangements, but by slowing the engine or stopping it entirely for short intervals. Most mines increase the diameter of the pump cylinders in the upper part of the shaft, but not all. The Requa shaft has pump cylinders placed on each side of the rod, which in ordinary conditions of drainage are worked singly, but can be doubled on requirement. For single working, the successive cylinders on alternate sides of the rod are used.

All the pumps on the Comstock are single acting; but the Alta mine at Devil's Gate has two spear-rods and pumps at both strokes, an arrangement which saves the use of balance-bobs. The cylinders of this engine also are compounded.

Though the cultivation of the soil requires artificial irrigation in this region, the vast quantity of mine waters are but little used for this purpose. Running into the gulches of Six-Mile Cañon and Gold Cañon, they serve to carry down the tailings from the mills where the ore is treated, and on their way are employed to operate a considerable number of blanket tables and pans for concentrating and treating the tailings. Finally they take their way to the Carson River, about seven miles distant by their route.

Looking to the future, it is not improbable that the problem of deep mining will meet its greatest difficulty in drainage. The heat of the mines can be controlled sufficiently to afford even better conditions for work at great depths than have been enjoyed hitherto. But the deepest points of excavation are already 1000 feet below the Carson, the drainage area has greatly extended, and must now interfere seriously with the natural channels of relief to surface waters over wide districts. The extraordinary persistence of the Savage water and its return nearly to its highest level during a three months' rest of the pumps, after losing more than 2,000,000 tons by pumping, has not been explained. Still it is true that the resources of engineering have by no means been exhausted in the present mode of drainage, and the new shafts will undoubtedly offer great advantages in this respect over their predecessors.

CHAPTER II.

THE COMSTOCK LODE.

THE great mines of the Comstock lode have twice been the subject of careful examination by experienced geologists. Baron von Richthofen, the earlier of these two explorers, brought to his task an unusual familiarity with the rocks in which this lode is found, and was able to fix, at one stroke, their age, their geological history, and many important points connected with the origin and history of the lode itself. ("The Comstock Lode," San Francisco, 1866.) His account was so thorough, and his view so penetrating, that he left comparatively little for the later explorers to add to the broader features of the subject. Mr. Clarence King, his successor in the field, while prosecuting the survey of the Fortieth Parallel in the service of the United States Government, was able to add to our knowledge of the rocks the important fact that the lode accompanies an eruptive dyke. He also greatly extended and systematized the points which Von Richthofen had merely outlined, and gave, in fact, the first detailed description of the numerous phenomena discovered by the mining explorations. Volume III. of his report is still the most important contribution which the history of American mining has received, and is not likely ever to lose its prominence and value. The work of both these gentlemen will be frequently referred to in the course of this memoir.

In addition to these professed geological treatises, Dr. Rossiter W. Raymond, while Commissioner of Mining Statistics for the United States Government, maintained a record of the mining works and the occurrence of ore bodies; but his labors were mainly directed to the task of illustrating the industrial operations upon the lode, rather than to a study of its geological character and history. The State of Nevada for several years employed a Mineralogist, whose published reports contain much information of value, though no careful study of the lode was made.

Von Richthofen's examination was made in 1865, closing when the deep workings on the lode were about 500 feet below the surface, though sinking had progressed to more than 700 feet at one or two points. During the interval of five years which passed before King's report was published, the mines deepened to 1100 feet at several points.

Abandoned drifts in these mines rapidly close up from the pressure of the ground, which has an extraordinary tendency to move and fill up any openings that are made in it. For this reason the task of studying its formation is unusually difficult; and no explorer can hope to go back upon the work of his predecessor and apply new discoveries to it. Each examination is made mostly in new ground, and has to stand for itself. Under such circumstances it is not surprising that the two elaborate descriptions of the lode which we possess are somewhat conflicting, though in unison in the main features of the great deposits.

My own examination was made nearly eight years after that of Mr. King closed; and consequently the depths open to me were entirely below those explored by him. It covered in general, the second thousand feet of depth, reaching from the 1000 to the 2000 level, and only occasionally surpassing the latter depth. In some of the barren portions, some ground that was seen by Mr. King is still open; but in the instructive parts of the lode the two explorations approach each other only at one point in the whole length of 20,000 feet under examination.

This lower portion of the lode presents greater unity and simplicity of structure than that near the surface. Above, the quartz was, for the larger part of the lode, divided into two and three parallel bodies by the fissuring of the hanging wall. Below, it is almost always single; and when divided by horses their dimensions are much inferior to the huge masses found at the surface. Above, there was variety of form, change in the direction of dip, and occasional unconformity with the west wall. Below, all these discrepancies are eliminated. Such a simplification of the conditions is, of course, an inestimable advantage to the student. The views presented here, which depart more widely from both the previous explanations than those do from each other, have the concurring testimony of three great bonanzas, one barren quartz body greater than any of the three rich deposits, and the country rock exposed in nearly 50 miles of openings to sustain them. The rock in the lower levels is mostly firmer than it was above, and the timbering is better, so that the whole of the ground mentioned, 1000 feet in vertical height, was open with very few exceptions. The maps which accompany this memoir have been treated so as to show just what portions of the ground were open and what were closed. In the latter case, the color which designates the kind of rock is continued over the lines of the drifts; but when the latter were open they are left uncolored on the map. Every part of the mine openings which is uncolored on the maps has been carefully explored and the rocks noted for their whole length. When ore has been extracted the main drift is most frequently kept open; but the other portions are allowed to fall in. This would be a serious hindrance to exact exploration were it not for the excellent maps which are maintained of these portions of every mine. The habit on the Comstock is to keep an accurate map of each level in a bonanza, and often of every floor. The levels occur in large bodies at distances of 50 feet, and in smaller, at distances of 100 feet. The floors are about seven feet apart. These maps give the details for a very complete cross section of the ore bodies, and the work is all careful surveyor's measurement. The method adopted of distinguishing between those portions of the mines which were closed and those which were open to exploration, by coloring over the former, makes unnecessary the use of dotted lines or other devices to show what parts of the geology are conjectural. Whenever lines are drawn away from open drifts and crosscuts, they are entirely conjectural, except in the case of ore extracted, and the nearness of the open workings is a good indication of the proportion in which fact and imagination stand to each other. Naturally the limits of the quartz bodies are most exactly known, while the position of the black dyke and of the propylite and diorite in the west wall are least developed by exploration.

THE SURFACE.

The topography of the Comstock is extremely simple, when the description is confined to the ore-bearing region, which is about five miles long and four miles wide. The whole of this area is the eastern slope of a mountain range which has an almost due north and south (magnetic) trend. Upon the bosom of this slope and near its eastern edge, are lofty hills of trachyte, rising 1200 and 1300 feet above the inclined surface on which they rest. Between them and the axis of the range lies a broad valley which has the trachyte hills on the east, propylite and andesite in its floor, and a more composite structure in its western boundary, which is the axis of the Virginia Range.

In the centre of this axis rises Mount Davidson, the highest of the peaks. This, with Mount Butler, immediately south of it, is diorite. North of this diorite mass the axial crest is composed of propylite, with some very limited exposures of metamorphic rocks and two small lines of diorite, exposed by the erosion of the propylite. To the south the ridge is also composed of propylite for about one mile, and of metamorphic rocks for another mile.

The outcropping of diorite through the eroded propylite north of Mount Davidson, is a surface indication of a fact that has been proved by explorations in depth, namely, that all this northern part of the crest is diorite thinly overlaid by propylite, and we may divide the ridge into three parts; and with odd coincidence, this three-fold division is sustained in its topography, its yield of ore, and in the human occupation of the ground. In the northern division we have the diorite region of Virginia, the loftiest part of the ridge, not merely in its isolated peaks, but in its average height. Here the propylite valley is narrower than anywhere else, and the trachyte hills which bound it to the east are higher.

Next southward we have the propylite part of the crest, with the town of Gold Hill and a wider valley in front of it.

Furthest on the south lies the metamorphic portion of the ridge, with the broad undulations of American Flat fronting it. Into the expanse of nearly four miles which lies between this crest and the trachyte on the further side of the valley, and about midway, presses a wedge-shaped mass of elevations formed of metamorphic rocks and the oldest and newest eruptive material of the region.

As the description proceeds, it will be found that these three localities, Virginia, Gold Hill, and American Flat, make three distinct divisions of the lode recognizable both by lithological and dynamic differences.

A complete description of the surface topography and geology is given in Mr. King's work. ("Report on the Fortieth Parallel Survey." Vol. III., Mining Industry, 1870.)

CHAPTER III.

THE LODE ROCKS.

A DISCUSSION of the theory of the Comstock lode will necessarily deal with the following prime factors:

1. The country rock, comprising diorite, propylite, andesite, trachyte, and metamorphic strata.
2. The quartz bodies: A. The barren quartz; B. The ore quartz.

It is proposed, also, to consider:

3. The dynamic movements affecting the lode rocks.
4. The cause of the fissures.
5. The shape of the quartz bodies.
6. The channel through which the fissures have been filled.
7. The date of siliceous formation, and also of subsequent metalliferous deposition.
8. The time involved in rock deposition and lode formation.

Von Richthofen was the first to show that the Comstock lode lies in rocks of late Tertiary age, comprising diorite, propylite, quartz, propylite, andesite, trachyte, and basalt, poured out in the order named. It is agreed among all the observers that his observations correctly defined the geological history of the country rocks.

THE COUNTRY ROCK.

Diorite. This rock is at once the most westerly in the Comstock region, and the oldest member of the series. It is exposed in two peaks—Mounts Davidson and Butler—already spoken of as occupying the centre of the ground. They are the loftiest of the hills immediately about the lode, being 7941 and 7450 feet high respectively. Mount Davidson forms the west country of the lode in the Virginia mines; but the diorite of Mount Butler does not appear in either the Imperial or Yellow Jacket, both of which lie upon its flank. Diorite does appear in the northern portion of the Bullion which lies opposite the ravine that separates the two peaks; and as this portion is opposite Mount Davidson, we may say with correctness that so far as the ground below the

1000 foot level is concerned, the diorite of Mount Butler does not enter into the number of the lode rocks. The reason for this is that Mount Butler is west of Davidson, "refusing" its flank several hundred feet toward the west. The black dyke and the quartz deposits which accompany it lie immediately at the contact of the Mount Davidson diorite and the overlying propylite, but at the point where this western trend of the diorite begins, the line of junction of the two rocks is abandoned and the dyke and lode continue southward on the course, nearly north and south magnetic, which they acquired in the Virginia section. A slight variation toward the west occurs at this point, but it is only two or three degrees. The maps show also, that there is in the Imperial mine a sudden set-back of the dyke also toward the west; but this amounts to only 500 feet, which is less than the westward trend of the diorite. It is, therefore, true that the dyke and lode continue southward very nearly on the same course they had in the northern portion of the lode; and as the diorite recedes toward the west, this direct course of the lode takes it into the propylite, which, in fact, forms both the east and west country in the Gold Hill mines.

Hitherto it has been common to represent Mounts Davidson and Butler as forming the peaks of a dioritic mountain, which, with other similar peaks not necessary to further mention, as they are not near the lode, stood as the Jurassic nucleus of the Virginia Range. Around these elevated peaks was poured the Tertiary propylite in a vast flood, overwhelming their bases and rising upon their flanks to some point not now discernible, perhaps, but certainly much above the present altitude of the propylite. Such an explanation of the phenomena carries, as a necessary conclusion, the former existence of a propylitic plain or slope with or without one or two diorite peaks rising through it. The present carving of the surface into steep hills and deep hollows must, under such circumstances, be entirely the work of erosion.

With this explanation I have not been able to concur. If the diorite existed as a mountain cone during the outflow of the propylite, the constantly expanding base of the cone should reveal this rock at points further and further southward as the mines increased in depth. The precise southern limit of the diorite is not known, but it is believed to have been always somewhere in the Bullion mine. If its slope is 45 degrees it should, on the 1836 level of that mine, be found about 1800 feet south of its junction on the surface. That would carry it south of the Imperial and Empire shaft, where careful survey in extensive drifts and crosscuts conclusively proves that it does not exist. Nor are any fluctuations in this line of contact reported. In short, every fact known of the diorite mass militates against the assumption that it exists in cone form on the south, for no extension in that direction has ever been discovered.

The facts gathered in the mines at the northern extremity of the lode are of a contrary kind, but equally conclusive against this theory of a dioritic cone. There this rock is found in every mine, from the California, which lies opposite Spanish Ravine, bounding Mount Davidson on the north, through the Ophir, Mexican, Union Consolidated, Sierra Nevada, and Utah, or more than 5000 feet of ground lying north of the diorite exposure on the surface. Instead of opening into the widening slope of a cone-shaped mass of diorite, these mines evidently are sunk on a lengthened ridge of that material. Yet the surface over them is covered by propylite which forms hills only a few hundred feet lower than Mount Davidson, as the following altitudes show: Ophir Hill, 7861 feet; Mount Abbie, 7439 feet; Cedar Hill, 7216 feet. The cone theory is not sustained, either where diorite is or is not found away from the Davidson mass.

In the extreme southern portion of the lode, the American Flat district, we obtain an isolated fact bearing upon this question, which could not be supplemented by more numerous observations, owing to the flooding of the mines during their temporary stoppage at the time this survey was made. After disappearing from the lode rocks in the Bullion and continuing absent through the Imperial, Jacket, Crown Point, Belcher, Overman, and Caledonia mines, the diorite reappears in the Rock Island. Between that and the Caledonia lie the Baltimore and other mines, none of which could be examined, so that the exact point of its re-entrance upon the scene could not be ascertained. But its presence in the Rock Island was proved by finding the rock in quantities on the dump, and I was informed that it had appeared on the 650 and 450 levels, where it was overlaid by a clay. As this clay occurs on the 200 level also, it is quite possible that the diorite lies near the surface. The clay possesses unusual interest from the fact that silicified wood, in blocks of considerable size, was found in it, the significance of which fact will be considered elsewhere. For the present we must content ourselves with the knowledge that diorite reappears in this portion of the country, a circumstance which, taken in connection with the foregoing facts, leads to the following explanation of the phenomena.

Instead of standing as a cone, the diorite lies in a broad, massive sheet, underlying the whole length of the Comstock lode. Dynamic movements have produced great folds in this sheet, and one of these waves now lifts its crest in the peaks of Mounts Davidson and Butler, while another, curving in the contrary direction, presents a deep basin across which the Gold Hill division of the lode lies like the chord of an arc. These folds diminish in height toward the south, and when the lode reaches the southern spring of the arc, it finds it still covered by its blanket of propylite, which has retained its place in consequence of the more level character of the ground and the diminished erosion.

The outcrop of this diorite sheet, if it were exposed through its whole length, would occupy a north and south line with a dip toward the east. Its surface, now hidden under the propylite, would show in the Virginia section a lofty east and west ridge covering the whole ground north of Mount Butler, and forming what may be distinguished as the Davidson uplift. In the Gold Hill ground would be a trough as grand in its dimensions as the corresponding elevation in Virginia. American Flat would probably present a ridge parallel to that of Davidson, but much lower. Lying upon these grand divisions of the sheet, exploration discloses a series of subordinate folds parallel to the great undulations, and modifying their contour.

The diorite, therefore, does not have the form of a cone or dome, but is a broad sheet thrown into folds, tilted, and outcropping at the point where the greatest fold intersects the crest of the inclination. The east and west strike of the folds in this diorite sheet indicate a north and south pressure.

The constitution of the diorite mass also supplies proof of its sheeted character. The surface shows some variations of composition such as are to be expected in all great bodies. Sometimes the rock is true diorite, entirely crystalline; sometimes amorphous or cryptocrystalline paste forms the basis of a rock that should perhaps be called hornblendic porphyrite rather than diorite, and, of course, there are variations in the proportions of feldspar and hornblende, and quartz is sometimes found in small quantity; but all these differences are considered to be quite normal and not indicative of the history we desire to trace. It is only when the diorite can be inspected in a tunnel that we obtain a hint of its composite structure. The following note of a hasty visit to the McKibben tunnel will serve to show that this mass, so long supposed to be an intruded or extruded dome, really presents very different characteristics, and is built up of successive layers. The distances are all estimated, and the direction is from east to west:

75 feet diorite.
7 feet diorite, decomposed.
225 feet diorite.
2 feet quartz, dip west and south.
15 feet diorite.
20 feet decomposed seam, some quartz.
15 feet andesite.
65 feet diorite, partly decomposed and with a thin dyke of andesite.
15 feet porphyrite.
45 feet diorite.
70 feet decomposed seam, with true Comstock blue clay, and dipping west.
60 feet solid quartz seam.
15 feet porphyrite.
35 feet quartz.
50 feet decomposed rock.
30 feet andesite.
15 feet diorite.
2 feet andesite.
25 feet diorite.
5 feet decomposed seam with quartz.
35 feet diorite decomposed next the dyke.
10 feet andesite.
10 feet decomposed rock.
35 feet andesite.
20 feet dioritic clay, dipping west.
5 feet decomposed rock.
20 feet andesite.

In this section diorite covers 592 feet, of which 117 feet are made up of seven seams of decomposed diorite. There are also three seams of 20, 70, and 5 feet thickness respectively, which are probably diorite; but are here distinguished from that rock because two of them contain some quartz, and the other is too much decomposed to make a correct determination possible in rapid inspection. Then there are three quartz seams of 2, 60, and 35 feet thickness, and six dykes of andesite 15, 30, 2, 10, 35, and 20 feet thick. But most surprising of all is the occurrence of 15 feet of porphyrite, which, so far from lying near the surface of the diorite, is 424 feet from the mouth of the tunnel, and in that position it would lie about 300 feet under the diorite if the slope of the rock is taken at 45 degrees. One hundred and thirty feet further another layer of porphyrite, also 15 feet thick, is marked; but the determination of this rock in the tunnel was doubtful and the specimen taken has not been seen since, so that re-identification is not possible. Both these determinations of porphyrite might be considered somewhat doubtful. Diorite and hornblendic porphyrite sometimes have such a very fine crystalline structure as to appear like a homogeneous paste, especially when seen by candlelight. They are then light gray, and resemble some varieties of propylite so much that they may easily be mistaken for that rock in a rapid determination; but King reports that the propylite penetrates the diorite "in well-defined dykes" in Ophir and Crown Point ravines, which are the bounding lines of the diorite on the north and south, so that the presence of this material in the tunnel is probable.

The McKibben Tunnel is opened in Spanish Ravine, which is cut in the diorite of Mount Davidson. The rocks exposed may be arranged in three groups. First, going west from the tunnel mouth, we have 344 feet of diorite containing comparatively little decomposed material, and only two or three thin seams of quartz. This is bounded by 15 feet of andesite dyke, which perhaps acted as a hanging wall to the formation that follows. The next 350 feet may fairly be looked upon as a lode in the diorite, repeating quite accurately, so far as one section can reveal it, the characteristics of the true Comstock. Only 150 feet of this is solid rock. Of the remainder, 95 feet is comprised in a massive quartz body. In approaching it, the explorer passes through 70 feet of a decomposed rock which may fairly be termed ledge diorite, to correspond with the ledge porphyrite of the Comstock. It has a blue clay and dips west. Then comes the 60 feet of quartz, and after 15 feet of intervening rock we have 35 feet more of quartz. That is succeeded by 50 feet more of decomposed rock, behind which lies andesite 30 feet thick, the black dyke of this formation. Here is a "vein" 230 feet thick. Its quartz is said to "assay," and occasional high assays from it are reported. This fact was not verified; but no one familiar with the Comstock would doubt it. Assays, and good ones, have been plentiful from the quartzes lying in the diorite, though none of them have yielded ore in profitable amounts. Still this is a silver-impregnated quartz body. It lies 1200 or 1500 feet west of the Comstock lode, or rather, of the position that would probably have at the level of the tunnel.

West of this vein and completing the section exposed in the tunnel is an alternation of four diorite and four andesite sheets covering 182 feet. This section is interesting because it presents phenomena which are supposed to characterize the black dyke also, that member of the Comstock being equally composite, though usually presenting thinner partings between the subordinate dykes which compose it.

It is to be regretted that on account of insufficient time the examination of the old tunnels which penetrate the diorite could not have been carried further. As it is, the exceedingly important labor of establishing the stratification of the diorite by full proofs, drawn from its direct exploration, must be deferred. Only a portion of the direct evidence can now be presented, and this must be allowed to obtain much of its force from its perfect resemblance to that afforded by the propylite. It consists of the occurrence of alternations of solid and decomposed or kaolinized rock, these alternations being sensibly banded, the presence of numerous andesitic dykes which have the same strike and dip, and the same regularity as those in the propylite, the occurrence of quartz veins of the first magnitude, the very existence of which in the Comstock rocks will hereafter be shown to be a proof of stratification—these strong points are thought to establish the case beyond question. To the observer whose conceptions have been formed in the propylite, there is not a moment's hesitation in announcing a perfect parallelism between the two rock systems in their structure and a partial one in their history.

The resemblance to the ordinary phenomena of the propylite is very minute. Quartz seams, or the ledge matter in which they lie, are bounded on the west by dykes of andesite, while the most solid masses of diorite are penetrated by thick seams of rock which have suffered extreme decomposition. Sometimes true plastic clays, blue in color, and perfectly resembling the well-known material which abounds in the lode, occur; but most of this degenerated rock is a highly altered diorite consisting of clay holding fragments of the solid rock, the whole mass being of a light tint. The entire correspondence of this material to seams which are elsewhere described in the propylite, shows that the diorite has had the same chemical history since its elevation as the former rock. This degenerated diorite differs from degenerated propylite only in its much lighter color. It is found abundantly in the Sierra Nevada, Utah, and Julia, all of which have extensive excavations in diorite.

The openings near the surface are not sufficient in number to prove the continuity and general parallelism of these seams of decomposed diorite, though the perfect resemblance of the ground in the McKibben tunnel to the propylite would, of itself, support such a decision. But the deep workings of the mines just mentioned leave no doubt upon this question. All of them have followed such decomposed seams for hundreds and even thousands of feet in a north and south direction. The seams are bounded by smooth plates of rock on each side, and show no tendency to a lenticular form, nor to the formation of unusual bunches. As to their origin, they may be the result of aqueous action on both sides of a crevice or parting, or the decomposition of one entire sheet in a system of strata, or, finally, the seat of chemical action may be a scoriaceous portion of an eruptive outflow. All these modes of accounting for the phenomenon lead to the same conclusion—that the rocks are regularly stratified; for it is not probable that such regularity of strike *and also of dip* would be obtained in the fissuring of a lava flood of vast thickness. These seams dip eastward with very few exceptions. If the explanation of eruptive stratification is accepted, this uniform east dip requires no theory to account for it. But if this is rejected, we are confronted by the supreme difficulty of showing what conditions of pressure or weight could propagate a vast number of parallel crevices at angles usually low, through a homogeneous mass of eruptive rock of great thickness. A special theory is needed to account for such a result of fracturing forces; and the difficulty of supposing it is evident from the fact that no one has undertaken the task. The inclination varies from point to point in depth; but the conviction obtained in years of mining is that parallelism is the striking characteristic of the Comstock in all its main features.

There are on the Comstock two kinds of crevices. One consists of the partings between successive thin outflows of melted rock. The other is composed of true fractures, and these are always broken through the hanging wall, and, in opposition to previous assertions, I hold that the latter are not parallel either to themselves or to the west wall, as the former are.

The propylite presents recognizable differences in the three regions which have been under examination—the Justice, Gold Hill, and Virginia ground. It is, in fact, *the* country rock of the lode; for while this occupies the contact line of the two formations, the quartz formations do not lie on either side of the junction, but are inclosed solely in the propylite, and they are divided from the diorite by the ever persistent black dyke.

While the grouping of a large number of old lithological species under the single term "propylite," by Richthofen, is undoubtedly a valuable service to geology, it is necessary for purposes of present description to revive some of the old names. There are, at least, three classes of this rock which show sufficient mineralogical and lithological differences to offer marked contrasts when viewed in place. These are porphyrite, quartz porphyrite, and hornblendic porphyrite. The porphyrite consists of light gray, sometimes white, light greenish gray, dark gray, deep green, and deep red paste, which often incloses a moderate quantity of glassy or milky crystals of feldspar. Hornblende is present in widely varying proportion. Large quantities of porphyritic breccia are found, in which the deep green variety, containing black hornblende, is disposed in fragments in a brownish red magma. Quartz porphyrite is mostly of a light buff or chocolate color, but sometimes gray, the base being studded with rounded grains of quartz, either glassy or tinted red by a coating of iron oxide. The hornblendic porphyrite is not the material described by King under that name, that being included here among the porphyrites. The term is used to designate a rock which appears to have the composition of diorite with the addition of an amorphous or cryptocrystalline paste. Milky crystals of feldspar and light green hornblende are inclosed in a base which is a compound of the two. This hornblendic porphyrite forms a striking component of the Justice rocks. The porphyritic breccia is found underground only in the Justice and southern Gold Hill sections ; but on the surface the hills adjoining Mount Butler are reported to be composed of this material (King, p. 7), and it is also found north of the lode.

The analyses of rocks from this region are not sufficiently numerous to determine whether these well-marked mineralogical differences are borne out in their elementary composition ; but until the contrary is proved, it appears to be unsafe to give analyses unless a precise description of the varieties treated accompanies them. While great differences in geological position are recognized, the rocks of the Comstock belong lithologically to one family, with the exception of superficial deposits of fragmentary strata, and they maintain close chemical relations of materials, which are chiefly composed of feldspar and hornblende.

The Gold Hill rocks contain mostly the light colored varieties of porphyrite, and it is indicative of the individuality which marks the three sections of the Comstock ground that the white propylite mentioned by King, in the upper levels of the Belcher, continues in the lower levels of that mine and into the Overman and Crown Point, its neighbors, but is hardly found out of that region. The Gold Hill rock contains fewer porphyritic developments than that of the other sections.

In the Virginia mines are found the light and dark gray varieties, and also those in which black hornblende is most abundant. Layers of the last mentioned variety are interspersed here among thick sections of the ordinary light gray non-porphyritic rock.

These different varieties of propylite are found in successive layers, all having a north and south strike, and an eastern dip. Even when layers that resemble each other most strongly are found in juxtaposition, they are separated by a continuous crevice. Quite often a series of thin layers of gray, purple, pyritiferous and non-pyritiferous porphyrite, perfectly separated, of uniform thicknesses, and lying in the same relation toward the other rocks, will be found in crosscuts several hundred feet apart.

The crevices in the mass are not irregular, but as even as those of limestone or sandstone. Occasional cross-seams and seams with west dip are found ; but not often enough to disturb the uniform regularity of the layers ; and they are not more frequent than in sedimentary rocks. Some of the layers are completely broken up by seams running in every direction, severing the whole into a mass of angular fragments of all sizes down to that of a walnut When these occur in the neighborhood of a dyke, the fissuring is explainable by the heat of the latter ; but the existence of thick layers completely shattered and at a great distance from any dyke must be due to dynamic action, and probably affords us an example of the mode in which the rocks were prepared for the deposition of quartz. These masses are a very interesting portion of the country rock. They are of all thicknesses, may be wet or dry, and showing no sign of ever having formed the channel of water currents. In other cases they contain clay, or show a minute deposition of selenite on the surface of the fragments.

Another striking fact noticed in the propylite is the entire absence of zeolites and of amygdaloidal porphyrite. The only considerable exception to this absence of secondary mineral products is found in the andesite dykes, which often contain calcite. The fine coating of selenite which communicates a sheen to the surfaces of some layers, is too delicate to indicate any other than the most trivial oxidation of the metallic sulphides which enter into the composition of all the rocks. Cavernous propylite is as unknown as amygdaloidal rock, but the thorough and regular decomposition of great seams, many yards in thickness, might justly give rise to the suspicion that some of these extensive seats of uniform chemical action were originally scoriaceous portions of the eruptive flows.

The clays which form so prominent a feature of the Comstock, are of every possible thickness, from a mere selvage applied to the contact surfaces of two contiguous layers, to a hundred feet or more in thickness. In the latter case they must, perforce, represent a layer of porphyrite highly altered, not only after decomposition, but also after the dynamic movements which placed it in its present tilted position had been completed. An equally extensive gradation is observable in the character of these clays, the thinner ones being plastic blue clay, the larger being masses of intimately mingled solid porphyrite fragments and clay. In this case the conclusion is almost irresistible that the seam once formed one of those fissured layers which have been described. In such material kaolinization would proceed with rapidity, and would not be confined to one side or the other of the seam, but would spread with some uniformity throughout the shattered mass. The alteration of the feldspar would not be local, but would proceed from all surfaces of thousands of fragments until a stage would be reached when the hard fragments would be converted to an equal number of clay masses, each inclosing a core of porphyrite. These kernels are found through all the clays of the region except the west clay of the lode. They have been described as pebbles, and the rounding of their angles attributed to the movement of the walls; but their occurrence in the heart of clay masses many yards thick disproves such an origin. Plastic clay would be the result of a more advanced state of alteration. While this decomposition is not local in respect to the horizontal section of such seams, it is sometimes local in the vertical sense. Seams which give the greatest trouble to the miner on one level, and require the closest timbering, are cut on another level and found to be perfectly firm, showing the result of localized fissuring.

The amount of clay in the Comstock rocks is enormous. The Sutro Tunnel cuts a great number of clay seams, some of them extremely thick, and for several hundred, and perhaps 1000 or 2000 feet from the lode, a change was noticeable in the whole mass of rock. It was degenerated, and the progress of the tunnelling was seriously delayed by the difficulties encountered in piercing it safely. The extensive character of this kaolinization is an extremely interesting phenomenon, and in the discussion upon the heat encountered in these rocks it will be found that I ascribe the high temperature so steadily maintained in the country rock to this felspathic decomposition.

One kind of clay seam which, from its nature, must be considered local, is the lode clay. Sometimes on both sides and sometimes on one side only of the quartz bodies, is found a blue clay known as the east or west clay, according to its position. In the Crown Point and Belcher, below the 1000 level, only the west clay was found, the quartz bodies ending on the east by mere abutting against the usual light gray porphyrite.* But in other cases an east clay has been determined on level after level, though there would be no quartz behind it. In such cases it is probable that some parallel clay outside of the lode has been accepted as an "east clay," on account of being in a position which corresponds with that of the true limiting wall clay on higher levels.

In the upper levels the clay seams were found to run in every direction, and all attempts to follow them and ascertain their relations were failures, but this diversity has almost disappeared in the lower levels. Irregular seams are locally found; but they are readily separated from the principal members of this class. The substantial regularity and parallelism of the latter are easily recognizable, and impress the observer with the belief that they cannot be the result of even the most regular cross fissuring.

More conclusive than even the evidence of the eye is the proof of stratification which is presented by the uniform eastward dip of the rocks. The regular partings in the propylite all dip eastward, and the entire series of rocks with its dykes, clays, and quartz seams, as they are disclosed in the second thousand feet of depth, have a dip parallel to that of the diorite in the Virginia section. This fact has been proved wherever this system of eruptive rocks has been penetrated for the whole distance of four miles to the Carson River. Its mere statement is sufficient to overthrow the idea that the diorite stood as a mountain already formed, while the propylite poured upon its flank in irregular floods.

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* It deserves to be mentioned that this disappearance of the east clay in depth was predicted by Von Richthofen at a time when all the levels within his reach contained a thick selvage on the east of the quartz. The confirmation of his prophecy is but one out of many evidences of his sound foresight which the subsequent exploration of this lode has furnished.

EVIDENCE OF TREE-GROWTHS IN THE PROPYLITE.

The history of this remarkable series of eruptive rocks receives additional light from the important discovery of fossil wood deeply imbedded both in the lode and through the whole propylite area. In the Rock Island mine, in American Flat, on the 450 and 650 levels, the "red clay" which, in the higher levels of the Comstock, took the place of the present blue clay, was found on the diorite, and upon the clay were found pieces of silicified wood, jet black, completely petrified, and of several pounds in weight. It has been found, also, in other mines, and stray pieces are taken from the surface, much worn, of course. In the Sutro Tunnel an unsilicified wood has been found in several places, and it has been met with in the shafts sunk to meet the Tunnel. Shaft No. 2 and shaft No. 4 have both afforded it, the latter at two levels. In some of these places it has been taken for a "coal seam" lying in a thin, rudely lenticular body a few square feet or yards in area. None of this material is silicified, the petrifaction of the wood substance appearing to be confined to the region of the lode; a fact which indicates that these rocks were not everywhere permeated by silica-carrying waters. Outside of the lode the wood is jet black, dark brown, and, more rarely, a lighter brown. It is very apt to contain layers of "mineral charcoal" which is sufficiently friable to smut the fingers. It has been pronounced a lignite by good authority, but its position in the heart of a vast series of old lava streams forbids such a conclusion. When isolated pieces of woody coal are found under lava beds there is but one conclusion—a tree stood in the way of the lava stream and was overwhelmed and converted to charcoal. Such an accident is an ordinary concomitant of volcanic eruptions. The intense black color of the silicified specimens leads to the supposition that they are petrified charcoal, but those which have been examined do not show any radial shrinkage cracks, like the charcoal burned in kilns.

Such a discovery would be interesting in any mine opened in solid rock, but on the Comstock it is a slender thread that guides us surely to important conclusions. The number of known localities where this lava-burned charcoal has been found is very much greater than the above account indicates. It has been discovered at several horizons from the surface of the diorite to a point three miles eastward, in the Sutro Tunnel. Its presence, wherever found, indicates a pause in the activity of eruption, a pause continued long enough for a soil to form and for a forest to grow. These soils are probably encountered in the mines, where there are irregular clay seams blacker than the ordinary blue clay and also of a different texture, and filled with quartz pebbles. There are also some brown and sandy clays occurring at depths much below the line of surface oxidation in the lode. The individuality of these peculiar members of the vein rocks was recognized long before the examination had progressed far enough to supply facts for the construction of a theory to explain them. The west or red clay lying upon the diorite may be looked upon as one of these soils, if the fragments of wood in the Rock Island were really lying upon it. This point could not be settled on account of the flooding of the mine. Clays which may possibly indicate such an origin are also found in the Crown Point 2000, the Ophir 1900 and 1465, the latter *in* the diorite instead of at its contact with the propylite, and also in the Savage. The fact that some of the Comstock blue clays lose their color and whiten or turn to a light fawn color under the action of heat, also indicates the presence of organic matter; and this may have a different origin from the hydrocarbons of lava. If there were no sustaining evidence, the reference of these irregular clays to ancient soils would be doubtful; but the finding of carbonized and silicified wood inclosed in the propylite brings a most conclusive kind of proof into the problem. It should be remarked that none of these fragments are water-worn, and that the woody texture is perfectly preserved. One of the fragments examined forms a quarter of a tree-section, and measures five inches along each of the broken sides, giving a *minimum* thickness of ten inches to the tree. The rings of growth are plainly visible.

In the Rock Island mine the vertical shaft is sunk east of the vein, and crosscuts are run westward to meet it, the crosscuts diminishing in length as each new level is opened in depth. These crosscuts have developed on the 200 and 450 levels a line of red clay slightly curved, and presenting the concavity of the curve to the east. Exactly upon this clay, and in the propylite immediately next it, the fragments of silicified wood were found. There is nothing in the situation to forbid the supposition that the trees grew where the fragments were found. This locality seems to have been a favorite one for tree-growths, for the fossil wood, always silicified, is found on the surface of the hill west of the mine. These specimens are, of course, weathered.

The imagination is not called upon to figure the state of things under which the Comstock lode rocks were piled one upon another, for we have just such phenomena before our eyes wherever volcanoes are active. An eruption covers the earth with bare rock, time brings a soil and a forest, and then another eruption, which sets the woods on fire, sweeps away the *débris* and overwhelms an occasional tree or stump. The only difference between occurrences which have been seen at Vesuvius and those which the exploration of the Comstock unfolds, is that one sends its melted rock in narrow currents from a volcano, the other poured out broad sheets of lava from long crevices. Otherwise their history has many parallel courses.

The discernment of these pauses in eruptive activity is of great importance in considering the time required for the formation of the Comstock system, which may be a type of the immense fields of eruptive rocks which make America the volcanic continent of the world.

Andesite. Though little andesite is found on the surface, the explorations underground have discovered a great number of layers of this rock, which show every sign of having solidified in their present highly inclined position They do not often cut across the propylite layers, though such spurs are found, but they frequently present, in a stratum of fissured rock lying next the andesite, the evidence of having intruded in a melted condition. This fissuring does not affect the whole of the porphyrite stratum, but extends only a few feet usually, it may be on either side of the dyke or on one only, and, indeed, the overlying rock appears to be more frequently fissured by the heat than the one underneath the dyke. Perhaps this is because the tendency of the propylite to break up after being subjected to the action of the heated andesite has been developed in the overlying rock by the percolation of water, or by dynamic movements from which the material under the dyke was protected by the covering position of the latter. The numbeı of these andesite dykes is unknown, but is certainly very large. We have seen that there are six in a thousand feet of the diorite. Three or four more are known in the propylite where exposed by the long crosscuts of the Consolidated Virginia mine. The Sutro Tunnel has intersected a very large number of them, probably more than are shown in both the above-mentioned localities. In fact, though nothing exact is known about them, it is quite safe to put their *minimum* number between twenty-five and fifty.

These dykes represent successive flows of rock, as King early perceived. Sometimes they occur in groups of thin dykes separated by very thin layers of propylite or diorite. This is the case with the black dyke, which has a centre of propylite, usually only five or ten feet thick, but with an unbroken extent of thousands of feet in length, and rising through the whole thousand feet of depth open to examination. The easternmost of the two sheets is much decomposed and frequently consists of a coal-black clay. Von Richthofen mentions that the west clay of the upper levels is free from pebbles, and does not have the swelling properties of the more easterly clays, and these are also the characteristics of this east division of the black dyke, wherever it is decomposed.

Considering the number and magnitude of the dykes, and the extremely limited outcrop of andesite upon the surface, we obtain a hint of the enormous extent of the erosion which has carved the surface. This erosion, too, was not a modern one, but was probably completed before the trachytic eruption, for patches of trachyte are found on low levels and high levels, lying immediately on the propylite, proving that the andesite was removed before the later rock was brought upon the ground. The andesitic outflows were undoubtedly very much greater than their remaining surface exposures now indicate, and they have played an important and peculiar *rôle* in the history of the lode. The usual eastern dip of the dykes indicates that they were injected between layers of rock already tilted to about their present inclination.

The great extent of this andesitic eruption is shown by the existence of considerable masses of the rock on the ridge of Mount Davidson and the hills adjoining, hundreds of feet above the loftiest outcroppings of the lode. From the crest eastward the dykes of this material succeed each other every few hundred or thousand feet for three miles. No regular variation in size is observable, thick and thin being sandwiched in together, but looking over the whole field, the series discovered in the Sutro Tunnel seems to be made up of thicker dykes than those in the western part of the ground, nothing like the massive Tunnel dykes having been found there. The black dyke, which has been so thoroughly explored that it necessarily stands as the exemplar of the whole series, shows occasional thickenings, the greatest being in the Crown Point 2000 level where it is a hundred and twenty feet thick. Such thickenings, however, cannot explain the great amount of andesite in the Sutro Tunnel, which continues on one level and would not be likely to intersect so many dykes precisely in their thickened portions. These thick dykes are two or three miles from the line of high peaks representing the crest of the range, and it is an open question whether their magnitude has not been the consequence, in part, of the heavy weight of andesite piled upon the ground from the numerous earlier crevices which had opened in the western part of the ground.

From the great swellings in the black dyke, which are shown not only in the Belcher and Crown Point but in the Consolidated Virginia, and perhaps other mines, we may derive the certainty that the ground moved in a vertical direction during this period of andesitic eruption. The strains to which the accumulated layers of propylite and diorite were subjected, produced that movement of crevice walls which is able to make thin nips and wide caverns out of ordinary undulations of the moving surfaces. The series of superposed layers slid upon each other and there may have been sufficient fracturing of the surface outflow to materially assist the extensive erosion which seems to have cleared the ground so thoroughly of andesite before the trachyte appeared.

The trachyte forms that line of lofty hills which have been spoken of as resting upon the inclined surface of the propylite two and a half miles east of the lode. Mounts Kate, Rose, and Emma, and the Sugar Loaf, composed of this material, are 6187, 6448, 6546, and 6164 feet high, and are separated from the diorite by a deep valley, of which the eastern slope is formed by these trachyte hills, and is quite abrupt. The western slope, on the contrary, is formed by the propylite, and is quite gentle, much more so than that of the diorite, with which it forms a continuous surface.

The three points of interest in connection with this new rock, are the dyke one hundred feet thick, discovered by erosion, which has cut down the trachyte to the level of the propylite at one spot, the patches of trachyte which are scattered over the valley and high up on the hills west of the lode, and the precipitous character of the lofty bluffs which the eastern side of the trachyte hills present to the Carson valley.

The dyke first mentioned was thought by King to be the channel of the whole mass of trachyte visible, but if the determinations of the miners in the Sutro Tunnel are to be depended upon, this is doubtful. The daily reports made in the progress of that work represent very extensive sections of trachyte, and it remains to be proved that they all belong to the surface overflow, and not in part to original channels of exit. It is true the very existence of so much of this rock in the tunnel is not established. The character of the rocks passed through rests upon the determinations of men who are well versed in mining but have no exact knowledge of lithology. The tunnel very much needs the attention of a scientific man for two or three months, and there is no doubt that its examination would establish valuable points in the geology of the lode.

A much more important fact is the presence of patches of the trachyte scattered through the propylite valley. Some of them are insignificant in size, but they are full of meaning as indications of the history of the lode. The ground east and west of the lode has been so well explored for a width of three or four thousand feet that we can say with great positiveness that no dykes of this rock exist near it. The diorite is entirely, and the propylite is for a distance of over two miles, free from its filled up channels of eruption. And yet this rock is found at a height of 6300 feet on Cedar Hill west of the Sierra Nevada, and perhaps at a point some three or four hundred feet higher. North of the Utah and about three thousand feet distant, is a large exposure of this rock, of which the crest is 6383 feet high.

In a north and south direction the line of trachyte hills mentioned above extends through the whole length of the Comstock region, but it is in the east and west dimensions of the outflow that we are to find its true significance. The outlying patches on Cedar Hill, at the New Jacket shaft, and opposite the new Overman shaft show that the propylite was once entirely covered by the later rock. The fact that the remnants of the great sheet are now found at a height of 6300 feet on the western hills, nearly two and a half miles from its origin, warrants us in supposing that the torrent once stood somewhat higher. Originally the trachyte must have formed a huge mass poured out upon the broad slope of the propylite surface, attaining an immense thickness at a distance of more than two miles from the diorite, and thinning out as its streams approached the edge of the basin, which they leveled off to something like evenness. Of this tremendous mass there now remain, near the diorite, but the few insignificant remnants which have been spoken of. For a mile and a half in width the rock has been swept away as the andesite was before it, leaving the propylite exposed with only an occasional outlier of the great covering sheet to mark the extent of its flow.

The full importance of this new element in the history of the vein, can never be understood until more accurate estimates of the thickness which was reached by the trachytic mass are obtained. The elevation of the bluffs above the propylite, or about 1300 feet, is the *minimum*, and the probable *maximum* is much higher, for there can be no doubt that the trachyte hills have suffered heavily from erosion. The precipitous heights composed of this material which overlook the Carson could not have been produced in any other way than by the cutting out of that portion of the outflow which extended over the present river valley. Whatever the exact dimensions of the flood may have been, it is certain that we have to deal with quantities and weights that are stupendous, and an effort will be made to show that it is to the action of these simple agencies that America owes her greatest deposit of the precious metals.

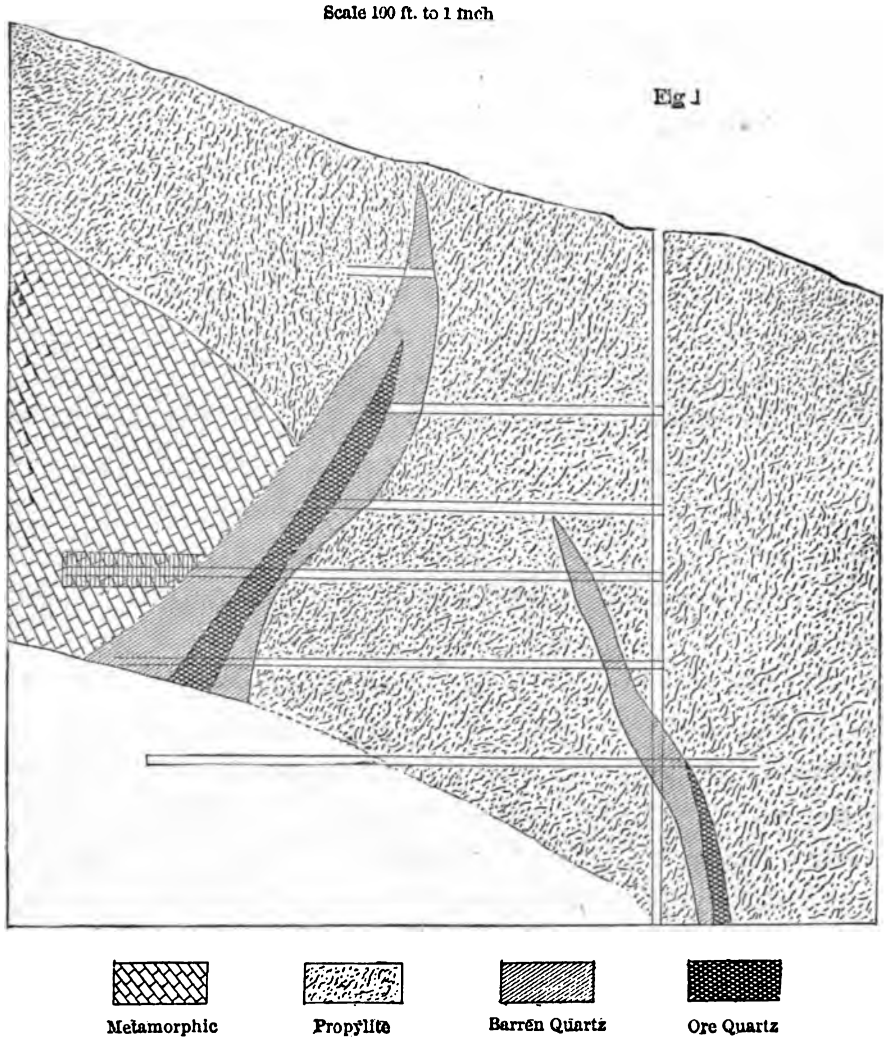
The trachyte has not been discovered in any of the workings upon the lode, unless we class among such works the mouth of the New Jacket shaft, where a small outlier of the rock is found nearly a mile east of the lode croppings in Crown Point ravine. The existing exposures of this rock appear to follow pretty closely the line of the western hills, a fact which is, no doubt, due to the excavation of a valley parallel to the diorite ridge, as the beginning of erosion. This longitudinal valley established its drainage to the Carson by Sugar Loaf pass in the Virginia section, and by the Devil's Gate in the southern part of the region, and the continuation of the agencies which shaped it has resulted in removing the trachyte down to the propylite in the longitudinal valley.

Metamorphic rocks. Upon the surface and within the first five hundred feet in depth on the lode, are found sedimentary rocks of all three classes—limestone, shales, and sandstone, but so highly altered that Mr. King reports a gradual progression from mica-schists to a rock indistinguishable from basalt. They are tilted to high angles, one observation being 65° east. As the lode does not appear to penetrate them anywhere, but is carried up in front of them wherever it enters their neighborhood, and as they appear at only one place in depth, they would hardly become a subject for discussion here were it not for their connection with the early history of the lode rocks.

The position of these rocks in the Comstock series has been so obscure that none of the geologists who have examined the ground has expressed a clear opinion concerning it. Von Richthofen merely says that the diorite "is probably a continuation of the granitic axis of the Pine Nut mountains and forms with the metamorphic rocks which accompany it the backbone of the Washoe mountains. The latter rocks join the syenite (called diorite in this memoir) to the north and south and are intersected by dykes of that rock, thereby proving its later origin." This author is probably correct in connecting the diorite with the neighboring granites, but the assertion that this eruptive rock penetrates the sedimentary strata in dykes has some doubt thrown upon it by the fact that the only dyke of this kind observed by me was composed of that variety of propylite which has been styled here hornblendic porphyrite. This rock has been called "porphyritic diorite," and "dioritic porphyry," but its geological separation from the earlier diorite is shown by its complete inclosure in propylite, forming sheets up to a hundred feet in thickness and proved to be continuous through workings a thousand feet deep.

Mr. King formed a conclusion on this subject which is based upon analogy with similar exhibitions in other parts of the West, and also upon the finding of Triassic leaves by Professor J. D. Whitney in Eldorado Cañon of the Pine Nut region, south of the Comstock. He says ("Fortieth Parallel Report," vol. 3, p. 14): "In *résumé*, it may be said that this range is one of the old Jurassic folds of stratified rocks, through whose fissures granite and syenite have obtruded; that after a very long period of comparative repose, from the early Cretaceous to the late Tertiary, the old range was riven in innumerable crevices and deluged by floods of volcanic rocks, which have buried nearly all its older mass and entirely changed its topography."

From this it would appear that Mr. King regards these sedimentary strata as the remains of Triassic depositions broken up by a Jurassic disturbance and ejection of diorite. His opinion certainly carries extraordinary weight, but there are facts which not only demand explanation before this view can be accepted, but also offer grave contradictions to the theory. It should be said here that the "syenite" of Mr. King, so far as it appears in the Comstock ground, was afterward determined as diorite by Professor Zirkel ("Fortieth Parallel Report," vol. 6, Petrography), and is so styled throughout this memoir.



METAMORPHIC STRATA AT YELLOW JACKET, WEST STREAK.
Probable Position.

Unfortunately, there are but very few significant facts concerning these rocks.

First, they lie between the diorite and propylite.

Second, they are not known to extend very far below the surface, with the sole exception of a small mass of limestone which is possibly referable to these rocks, and is found in the Sierra Nevada 1450 feet below the mouth of the shaft.

Third, in the two cases where their surroundings have been observed, they stand upon a flattish fold or table of an underlying rock, and extend up to the edge where the dip suddenly increases, but do not follow down on this greater dip.

This singular position is visible in the Yellow Jacket and the same state of things is partially made out in the Justice, with the exception that the flat underlying table is not developed by the workings there. In both cases the lode has a *western* dip opposite the metamorphic rocks but inclines in the contrary direction below them. The situation in the Jacket west vein is shown in the accompanying cross-section taken from King. The propylite, ore quartz, and barren quartz are given as his map shows them, and the metamorphic strata have been given a conjectural form. They are exhibited at only one point in the workings, where the 360 foot level has penetrated them for a distance of seventy-five feet. In the Justice an andesite dyke lies along the combined face of the metamorphics and the rock which underlies them, and probably this was the case in the Yellow Jacket also. In both cases propylite forms the country east of the ore body.

The heavily shaded part marks the only position where the presence of sedimentary rocks has been actually proved.

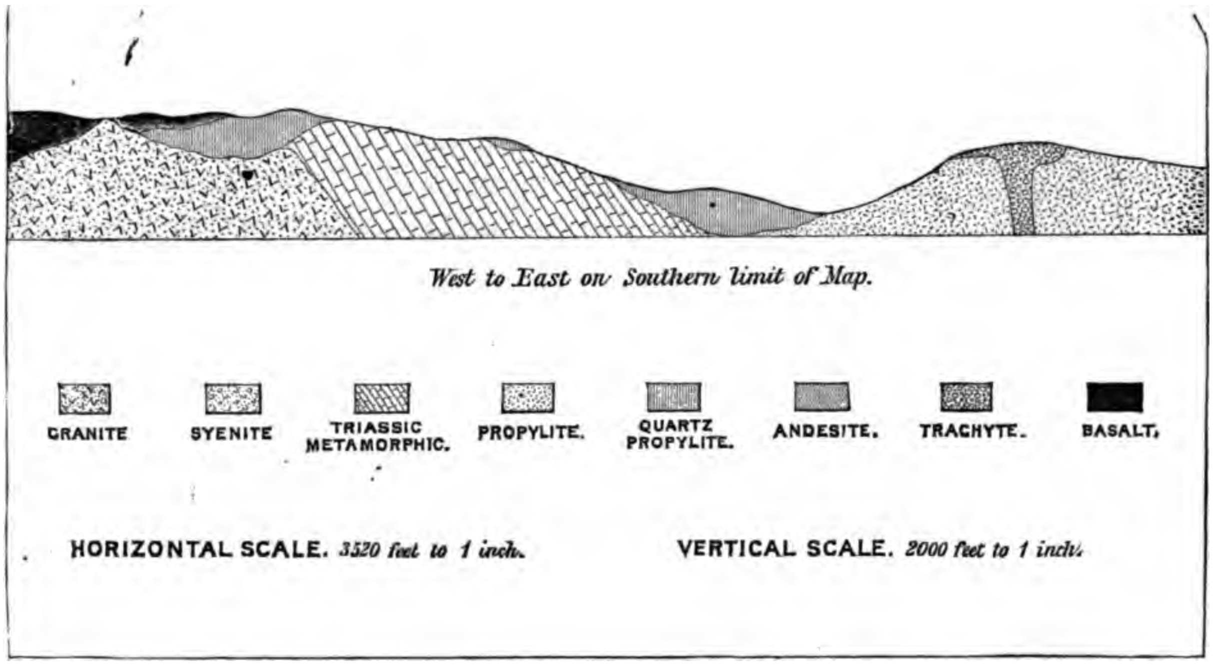
It seems almost impossible to suppose that these metamorphic rocks are the remnants of an old surface through which the diorite burst, either in one or several eruptions. The latter rock has a thickness of several thousand feet, and its relations to the metamorphic strata do not exhibit the signs of an overflow upon them. It is not known to cover the metamorphic layers, but, on the contrary, constantly carries them on its back. If the diorite is too great for a dyke, and is not an overflow, we must either revive the notion of a protruded dome of this rock, or reject the idea that it is younger than the sedimentary rocks now disposed upon it. In discussing the diorite it has been shown that it is not a dome, but a sheet, and there is probably a more natural explanation of the facts than the current one.

Lying between the two important divisions of Comstock rocks, the first deduction from the position of the metamorphics would be that they are younger than the diorite and older than the propylite, and no downright observation of fact has ever been brought forward to contradict this inference. That is the most probable supposition, and there are positive proofs to sustain it.

This evidence is partly in the character and position of the diorite, the approximate conformability of the aqueous rocks in dip to that rock, and, finally, in their extremely limited distribution.

While the erosion in the Comstock region has been immense, there has been no important eruptive overflow which has not left scattered traces to mark its extent. Nothing of the kind is visible in the diorite, and even where it or its congener, granite, merely peeps through a wide area of metamorphic rocks, as in the southern part of the field, the *habitus* of the exposure is so plainly not that of a dyke that no observer hesitates to mark it as a surface upon which the so-called Triassic rocks repose, and it is given this position by King. There has been no overflow of diorite to cover the latter, which overlie the

FIG. 2.


West to East on Southern limit of Map.
GRANITE
SYENITE
TRIASSIC METAMORPHIC.
PROPYLITE.
QUARTZ PROPYLITE.
ANDESITE.
TRACHYTE.
BASALT.
HORIZONTAL SCALE. 3520 feet to 1 inch.
VERTICAL SCALE. 2000 feet to 1 inch.

RELATIVE POSITION OF THE COMSTOCK ROCKS.—FROM CLARENCE KING.

eruptive rock wherever it is found, and are in their turn overlaid by propylite.

The stratigraphical relations of the two classes of rock are well exhibited in the section (page 55), given by King, of the country lying in the southern part of the Comstock region. Here, there are wide exposures of the metamorphic strata, and through them is visible a small outcrop of granite. Though Mr. King's view of the history of these rocks differs from that here presented, the section seems to support the opinion that the sedimentary strata were deposited on the granite and were subsequently covered by propylite and quartz propylite.

The dip of the sedimentary strata is 60° to 65°, and somewhat higher, to the east. It conforms very closely to the angle of the diorite where exposed above the propylite, and is rather more inclined than the latter. The strata appear to be conformable to the former, but observations on this point are very scanty.

The total disappearance of the sedimentary rocks in depth could hardly occur if they formed an old mountain chain through which the later lavas had burst. There is not a trace of them below four or five hundred feet from the surface, even in the Silver City part of the district, where they have their largest exposure. There they are cut through by dykes and metalliferous quartz veins. What lies below them is unknown, except so far as one outcrop of granite indicates. If this is the rock beneath them it would establish the interesting fact that the Justice and its neighboring mines are in the same situation as the Comstock—a contact lode in propylite near granite.

These facts are strongly opposed to the theory that the rocks in question are the remnants of an old fold which has been broken up by eruptive intrusions. They are not sufficiently disturbed to allow that explanation, and it is more probable that the diorite, with which must probably be reckoned the granite as a siliceous portion of the same mass, is the oldest of the visible Comstock rocks. It covered a large extent of ground and was subject to marked oscillations of level, during which these sedimentary rocks first accumulated, and were then elevated and partially removed by erosion. Such an occurrence as that of the Jacket is explainable by the supposition that the sedimentary strata which now rest on a fold of the underlying diorite once covered it, but were removed from the uplift by erosion, and left undisturbed only in the trough, which was afterward lifted by a more general movement, into the highest position.

Still, the evidence is contradictory. Professor Whitney found Triassic leaves in beds similar to these in Eldorado Cañon, south of the lode district. The diorite and granite, on the contrary, are assigned by Mr. King to the late Jurassic, at which time he considers the folding of the accumulated strata took place. One or the other of these determinations is incompatible with the view here brought forward—and there is nothing in the Comstock to decide the question. It is one which must be left open, and it is touched upon here merely to bring forward the fact that there are grave contradictions to the existing theory of the relative age of these two rocks. It has been seen that the interior constitution of the diorite mass is such as to forbid the idea of homogeneous injection, or of dyke formation. In the remarks which follow, the evidence of the metamorphic series will be neglected as being too obscure, and the story of the lode rocks will be read as it is indicated in the eruptive members.

CHAPTER IV.

THE HISTORY OF THE LODE ROCKS FROM THE BEGINNING TO THE FORMATION OF THE QUARTZ BODIES.

THE character of the country rocks and the conditions under which they occur having been examined, we are now in a position to ascertain whether the observations made can be assembled so as to afford a rational explanation of the geological events which prepared the ground for receiving the great lode. The grand fundamental fact which the foregoing pages have been written to establish is that the whole mass of diorite and propylite is not to be considered as one or two, or any small number of outflows, vast in thickness and irregular in shape, but that they form a series of thin, bedded, regular layers of rock superposed in a definite succession and presenting a fine example of eruptive stratification. Through this system of bedded lavas have burst two later rocks, the andesite and trachyte. Confining our attention now to the diorite and propylite, it is evident that they must have been laid down in horizontal sheets and tilted afterward.* This movement of elevation after horizontal deposition is one of the plain features of the Comstock region, for there is no other explanation that can account for the constant parallelism of the propylite with the diorite. The region contains immense exposures of material that is plainly uncomformable to its geological predecessor; but the proofs of this which are so evident in the overflows of andesite and trachyte are entirely wanting at the junction of the propylite and diorite. The andesite dyke which separates them is essentially parallel to all other dykes of its system, whether east in the propylite or west in the diorite. But if dykes were intruded at the contact of the andesitic and trachytic surface rocks with the propylite, they would not be parallel to each other or to any member of the whole series. This difference is due to the interposition of an elevatory movement taking place between the eruptions of propylite and andesite, and disturbing the previously regular building up of the layers. This movement of elevation may have been nearly completed before the appearance of the andesite. The scattered remains of that overflow are too insignificant to allow the definite settlement of the question; but it is certain that the uplifting force continued in action after its appearance.

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* It is plain that the facts noted here give support to Mr. King's theory of the mechanical origin of the granitic rocks, and appear to bring the Comstock diorite into the same category. The connection of this rock with the granite of the Justice neighborhood, and other granites of the Virginia Range, add strength to the supposition. But the present work was entirely written before Vol. I. of the Fortieth Parallel Report appeared, and no alteration of its phraseology was thought advisable. Its descriptions will remain sufficiently clear, whatever origin may be assigned to the diorite hereafter.

The uplifting which is so plainly indicated by the striking difference in the position of these rocks casts an effective light upon the circumstances under which the two earlier members were laid down. The seams and partings that now stand at angles of from 35 to 60 degrees, were horizontal before that action took place. The evidences of this in the propylite are too plain to be mistaken, and though the diorite is less explored the phenomena observed within its mass throw the strongest probability upon its stratification.

We must, therefore, picture to ourselves a time when from a system of fissures the position of which is now unknown, streams of diorite were poured out upon a level country, covering it with a succession of thin layers. Dynamic movements began before the appearance of any propylite, and the three divisions which are now recognizable in the lode were thus early outlined. The Virginia section was raised as a broad fold, the Gold Hill portion was sunk in a trough, and at American Flat probably rose another crest of less altitude than its Virginia neighbor. These variations in the diorite surface may have been less strongly marked at first than they now are. But it is also perfectly evident that the foldings of the black dyke are less in amount and do not correspond in the smallest degree to the great Gold Hill trough. If the black dyke there occupies a true fissure broken across the arc of the trough as the shortest line, this inconformity would be the result of movements that took place in the earlier part of the andesitic period. But it is quite as probable, or more so, that this great trough was levelled up by early outflows of propylite to about the height of the diorite wave in Virginia, and that the dyke in Gold Hill occupies a line of partings between successive propylite floods, and not a fracture. That view is accepted in this memoir on account of the magnitude of the undulations in the dyke, it being believed that these are more prominent than would be the case if they were entirely the product of movements that occupy only the declining stage in the dynamical history of the region. If the dyke in

Gold Hill is bedded, as it undoubtedly is in Virginia, its undulations represent movements that affected the rocks before it appeared.

To the diorite thus partially moulded came the propylite, not in a few mighty currents, as the idea seems to have been heretofore, nor in a steady succession of overflows, but in a series of alternately active and inactive periods. A number of flows would be poured out with too great frequency to permit much alteration of the surfaces, and then a pause would follow, during which a soil would accumulate by ordinary atmospheric agencies, and vegetation would spring up and continue until trees of considerable size had been produced.

The outpouring of propylite continued until a great thickness of this material had accumulated, for the propylite extends 20,000 feet or thereabouts from the lode. If this is tilted at an average angle of 35°, it would have a thickness of between 11,000 and 12,000 feet, and these numbers may be taken as an approximation to the truth. The forces which had acted upon the diorite continued, increasing the undulations of that rock and forming waves in its successor.

These dynamic movements were twofold, their lines intersecting at right angles, and it is necessary to obtain a clear conception of the compound results produced, for it is upon them that the position of the quartz and ore bodies entirely depends.

The first in prominence, though perhaps the second in point of time, was the movement which raised the Virginia Range to its existing altitude ; and as the crest has a meridional direction, the action of the force was east and west. So far as the limited area of the Comstock region is concerned the result was a grand elevation, the eastern slope of which was covered by a series of lesser folds parallel to the first, but so much less prominent that they merely gave a waved outline to the surfaces of the strata. Had this force acted alone the result would have been a broad slope fronting the east, and covered by low folds trending north and south with the main crest. These folds were repeated downward through layer after layer of the series.

This simple example of ordinary elevation was acted upon by a pressure in the contrary direction, or north and south, and the consequence was the production of a precisely similar series of folds composed of one grand and many lesser waves. These all strike east and west, or directly across the former. As all the waves of the second system appear to be of less magnitude than those of the first, the north and south will be styled the PRINCIPAL, and the east and west will be called the SUBORDINATE folds.

Both of these systems are developed in the progress of the mining operations. It has already been said that the dip of the rocks changes constantly, thus marking the surface of the low waves produced by the principal movement, the Virginia Range being its great uplift. Similarly the workings along the strike have shown that this also has a waving line. The latter folds not only belong to the subordinate system, but they are only the lesser members of it. Its greater features have already been described as an uplift in Virginia, a great trough in Gold Hill, and probably a second but lower elevation in American Flat.

The intersections of these cross waves would mould each layer of the propylite and diorite into a checkered system of low domes and shallow troughs; and it is by the subsequent forcible alteration of these domes under peculiar circumstances that the eruptive strata were opened for the deposition of quartz.

By the operation of the principal movement of elevation, this whole system of domes and basins has been tilted to such a degree that their slopes give angles that vary between 20° and 70° as extremes, but more commonly between 35° and 65°. It is not to be understood that the rock surfaces are covered by regularly disposed mounds. On the contrary a comparison of dips and strikes at succeeding levels of any mine will show the greatest diversity in the position and shape of the elevated points which mark the crossing of the two systems of fold.

Each of these systems has one great elevation as already remarked, and at the point where the great folds of the two opposite pressures intersect, stands Mount Davidson, the apex of the whole net work. Extensive erosion followed the uplift, and at this point the propylite was swept entirely away, leaving the diorite to stand in the bold peak that has so long been looked upon as a nucleus cone of an ante-propylite mountain range. The work of the eroding forces which have carved the successive surfaces of this region does not appear to have been estimated hitherto at its true value. In the continuation of this subject it will be seen that its effects have been extraordinary.

The movement of elevation culminated in the production of fissures, probably a score or more in number, through which rose a new rock, andesite. Except in a few doubtful instances, these fissures nowhere break through the layers, but lie always between them, the only exceptions observed being in the case of the " branch dyke" in the Imperial (if that is one, and not one member of the composite dyke which follows a bend in the propylite), and in a few dykes which locally show a west dip and may be spurs into the hanging wall. In the Imperial the fissure after passing the great fold in the diorite on its southern course, turns westward for about 500 feet, and joins another fissure which seems to continue its course without such a change of direction. But this exception is confined to one of the many dykes, and that one is the contact dyke lying between the diorite and propylite. Its change of course occurs a short distance after leaving the line of contact and entrance into the propylite.

The injection of andesite was accompanied by the usual movements of fissure walls. The hanging wall slid down upon the foot sufficiently to alter the old juxtaposition of surfaces and bring concavities together, so that the thickness of the opened seams was locally altered, being enlarged in some places and diminished in others.

Though the surface shows little trace of the presence of andesite, it is probable that this period produced eruptions of the first magnitude. It is impossible to suppose that the numerous and massive dykes of this rock represent surface overflows of only secondary importance. With much more probability we may regard the andesitic eruption as third in importance, possibly surpassing the trachyte in the quantity of materials ejected in the immediate Comstock region. The propylite must have been covered to a great thickness, and what was once a diorite, and then a propylite surface, became through the length and breadth of the Lode country an andesite surface. That only the most trivial remains of this great series of eruptions are now left is a mark of the powerful decomposing and eroding forces which acted there after these outbursts were finished, and a sign of the immense lapse of time during which that erosion was in progress.

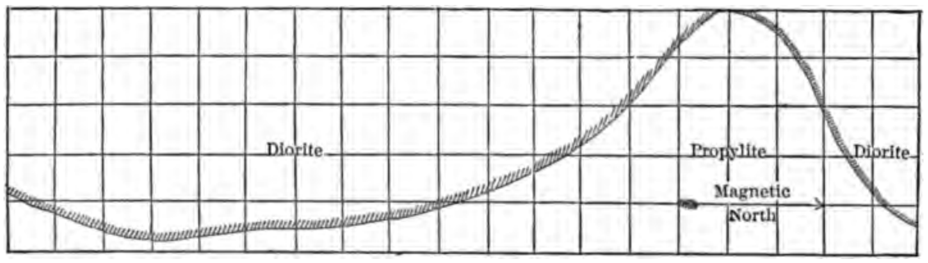
But though these remnants are small, they are by no means insignificant in other respects. They are so disposed over the varied surface as to convey the strongest proofs of the great extent of the parent mass.

The overflows of andesite dot the upturned edges of the propylite at so many places that they indicate the certainty of a sheet which once covered the whole propylite surface, while the occurrence of the same material in considerable fields high up on the hills above the lode is evidence of the great thickness which the piled up eruptions may have reached. I have ventured to look upon the presence of this vast mass, and the pressure which its weight exerted upon the edges of the diorite and propylite, as one of the three elements which combined to form the first cause of the great lode.

It has been pointed out that the subordinate pressure raised a succession of ridges in the layers of propylite and diorite; and it will be shown hereafter that the relation of the quartz bodies to these elevations is such that the history of the lode is evidently to be read from the indications presented by them. Fortunately their characteristics are strongly marked. Being raised under the cover of other strata these ridges should offer pure contours of elevation, unaffected by erosion, for they have never been subjected to atmospheric action; but such simplicity of structure is not found in any part of the lode. Their form has been disclosed with great exactness by the continuous series of mines through a length of 16,000 feet, and nowhere are the undulations found to present a shape which can be called normal. The ridges are broad, low, and flat, the troughs narrower and consequently deeper in proportion to their width, the dividing line between uplift and trough being taken at the middle of the slope. Together they present an outline that is irreconcilable with our conceptions of unrestrained folding.

These peculiarities are presented in a typical manner at several points in the thousand feet of depth which came under my observation, and notably in a remarkable "horse shoe" drift in the Overman, and in a trough in the Imperial. Unfortunately neither of these is shown in the accompanying maps; but the variation of the contour from the normal is well exhibited in the Gould & Curry, 331 feet below croppings, and Mr. King has figured this in his Atlas plate number 11. An outline copy of this is shown in figure 4. Dividing the slope at its centre we have a trough 500 feet wide and 250 feet deep; and an elevation which the incomplete outline shows to be more than 1300 feet wide, with the height of 250 feet. The whole width of the uplift is 1600 feet. The sides of the trough have a slope of nearly 45°, and in passing it the quartz bodies leave the west wall and break through the propylite 700 feet east, where its layers were less compressed.

FIG. 3.



HORIZONTAL OUTLINE OF WEST WALL IN SAVAGE MINE,

331 FEET BELOW CROPPINGS.

Scale 400 feet to 1 inch. Squares represent 100 feet each.

In considering this figure it is to be remembered that the diorite is the underlying rock, and that the bold part of the curve represents a deep sinus within its mass. The corresponding uplift is much gentler in its outline, and this low prominence and long sweep are characteristic of most of the elevations upon the west wall throughout the lode. It is considered that these easy curves indicate the action of a moderate, steady and long continued pressure, and that the sharper outlines of the troughs are foreign to the undulations which would be formed by such a pressure acting upon strata that were free to yield toward the surface. Their existence will be explained by a hypothesis that rests upon a threefold assumption:

1. That the present outlines are abnormal:

2. That the normal outline of low folds produced in freely moving strata would have shown greater equality between the breadth of the uplifts and downthrows.

3. That the outlines were normal so long as the action was confined to the rocks which compose the folds, and that the change of shape was produced by the intervention of a new dynamic element.

This new element was the introduction of the andesite which follows the propylite in order of time. It has been shown that though the exposures of this rock are small, they are disposed in a manner that proves them to be mere remnants of a great mass, and it is to be remembered that though this rock holds perhaps the third place among the Comstock series by the magnitude of its outflows, it had no union whatever with the diorite and propylite that preceded it. A movement of elevation had intervened, which prevented the andesite from continuing in the orderly arrangement that had built up their double mass, and it was accordingly deposited upon their upturned edges.

During the movements which elevated these rocks before the appearance of the andesite, the strata had been free to fold in obedience to the pressure exerted on them. Now they were no longer free at the surface, but were held down by an overpowering weight of andesite, and the several layers of rock were unable to continue their regular folding. The domes which irregularly checkered the surface of each stratum, marking the intersection of two cross-lines of folding, could not keep up their rising movement, for the andesite which now lay upon them was a mass entirely extraneous to the stratified series in which the folding took place. It was a dead weight supported by the strata, but not partaking in their history nor sharing the effect of the force that was moulding them. It was a case where the irresistible met the immovable, and the result was a compromise. The folded layers found another mode of adjustment to the pressure.

Pressed upward by an overpowering force against the rigid cap, the layers of these domes were compelled to an alteration of shape in another direction. The same power which tended so strongly to raise the crests also tended to deepen the troughs between them, and in this direction no unusual obstacle was met. Here a certain amount of relief was obtained by the sinking away of the troughs, and into this opened ground the strata of the folds were squeezed sidewise. The once regularly curved and normal domes were thrown into distorted shapes, and the troughs between them, instead of showing the even curves which folding so moderate as this necessarily produces, were forced out of their proper form so completely that their misshapen contours have always been mistaken for deep ravines of erosion, which were supposed to have been cut in the exposed surface of the dioritic peak.

The strata of the uplifts being pressed sidewise into the troughs, the latter would find themselves invaded from both sides, and their filling up would continue until the two waves of translating uplift would operate against each other. *Then* would begin, at length, the action which was the first immediate preparation for the coming lode.

In any fold composed of concentric layers, the outer strata are necessarily longer for a given segment than the inner, and if the fold is pressed flat by a force that is propagated from the crest toward the trough, the upper strata must either slide further or arch themselves over the lower. In the present case they reached a point where they could not slide further, being met by movement from the opposite side of the trough, and accordingly when this contrary pressure was felt the successive layers were arched over each other in proportion to their different lengths. This arching of course took place not in the crest of the fold where the weight was felt, but on the shoulder of the ridge. It was in fact no more than an arrested wave of translation. An experiment made with a flexible book will produce just such a dome and flexure as were produced in the propylite under the circumstances here considered. The amount of this arching was probably very small, comparing the successive strata together. The layers may have been hardly more than separated, leaving a mere parting between them ; but as they were superposed they formed, taken together with the intervening layers of rock, just such a concavo-convex lens as we find at the bend of the quartzes. In these narrow partings between the strata quartz was deposited, and the immense bodies which now exist have been formed by the union of a great number of these insignificant seams through the removal of the intervening propylite, and its replacement with silica.

While the crevices produced in the strata were not great in size the wave of translation appears to have presented a very bold front, for the bend in the quartz bodies, which now occupies the front of the wave, is very decided in the three examples which were under examination. The quartz sometimes turns from almost entire parallelism with the dyke to a direction almost at right angles to it.

The size of the domes produced by this pressure under conditions of confinement is probably represented pretty closely by the present quartz bodies. These vary in an extreme manner ; but are often from 1000 to 1400 feet long, and as great in their dimensions on the dip of the lode, while the elevation is 200 or 300 feet measuring from the centre of the slope, and the surrounding troughs may be but 400 or 500 feet wide. From such proportions we obtain a hint that the reduction of the height of the folds may have been considerable. The present aspect of the formations is no doubt very different from what it was when the andesite was poured out upon them.

Among the irregularities which are discernible in the strata the great Davidson fold holds the most prominent place. That peak occupies the point where the crest of the largest subordinate ridge surmounts the grand elevation of the region, or rather what is left of it after an erosion that appears to have been enormous. The lesser waves upon the front of this great subordinate fold have been moulded, like all others, by pressure against the andesite; but the great fold itself seems to have resisted the flattening process which moulded the lesser heights, and acting as a rigid mass it has had its special effect upon the lode. While this greatest of the subordinate folds preserves its prominence through the whole of the Virginian section, its highest point is opposite the Bullion and Chollar-Potosi. From that line the contour falls away on both sides and two of the largest and most continuous quartz masses lie immediately north and south of this rib, the Chollar-Potosi and the Yellow Jacket. Probably these are the largest accumulations of quartz in the district, so far as explored, and their position on the flanks of an immovable ridge show that the latter acted as an abutment to the moving strata when they were forced to change their position under the steady pressure from the north and south. The Gold Hill propylite pressed squarely against the broad side of the Davidson fold where the diorite was turned back westward in its grand curve to the south. Here the strata appear to have spread apart quite regularly in the lower levels where the results of the pressure were not influenced by the nearness of the surface. On the northern, or Chollar-Potosi side of the uplift the pressure produced no results at all below the third station, 711 feet below the shaft. There the propylite and diorite are in close contact and have continued so for more than 1500 feet of further depth. Above that limit there was an immense accumulation of quartz, holding several distinct ore bodies united by low grade ore.

The quartz bodies occupy the domes which have been described, but usually lie only on one side of them, only one case being known in the lower levels of a quartz which completely encircled one of the larger swells of the west wall, though they pursue the smaller undulations which wrinkle the broad curves without undergoing any apparent change. Their position may be on either the north or south side, or on the east of the dome, the latter being undermost in the inclined position. But they are not found on the west or upper side, though a leader from the large mass in the trough may run up in this direction.

Their form is very peculiar among such bodies, but it is also quite uniform so far as the deep workings are concerned. They all start from the black dyke beginning in a thin edge or point which projects out from the dyke into the propylite, following the slope of the domes and turning sharply over the abrupt crest, from which point they continue in general parallelism with the dyke, sometimes near, sometimes widely separated from it. Their greatest thickness is exhibited at the crest and on the slope just below it, but is not carried down into the bottom of the trough, though the mass may continue in about the same thickness for some hundreds of feet on the flattened back of the dome. (See the Jacket quartz, Plate II., Crown Point, Plate II., and Con. Virginia, Plate IV.) Ultimately the quartz thins steadily to the merest seam, and it is interesting to observe that the continuation of this quartz seam may be a clay reaching for a considerable distance further. This has not been positively shown in any great bonanza, as the pursuit of the seam ends before this point is reached. But it is constantly exhibited in lesser seams cut by chance in the drifts. This gradual decrease is probably the mode in which the Crown Point-Belcher quartz ends; but the posterior termination may also be as rapid in its change of thickness as the anterior always is. An instance of this is found in the Consolidated Virginia bonanza, which has the form of a thick lens, but a lens in which the convex side is more like a cone that a curve, so rapid and great is the thickening.

There is no uniform direction for the course of these bodies. The Crown Point and Belcher starts from the dyke and runs southward. The Consolidated Virginia and California runs northward, the bend toward the dyke being at the south end. The Justice runs north-eastward, and this diversity removes any suspicion of magnetic influences. The true explanation is to be found in the dynamic movements of the lode rocks.

All these peculiarities of the quartz bodies are well exhibited in the four great examples which are delineated in the maps of the Consolidated Virginia-California, Crown Point-Belcher, Yellow Jacket, and Justice.

The constitution of the quartz masses has never yet been satisfactorily set forth. In fact, the upper portion of the lode has suffered from so many distracting causes that their true composition may have been entirely masked there; but in the second thousand feet of depth the formative processes have not lost their simple character and their action can be clearly studied. There the quartz bodies bear evidence in support of nearly all the positions taken in this memoir.

In the Yellow Jacket quartz especially, but also in every other deposit now open to inspection, the proofs are plain that these bodies are never homogeneous throughout. Even when on some levels they show 300 feet thickness of solid silica, as in the Jacket, they betray on other levels the fact that they are composite structures of propylite and quartz disposed in parallel layers. Nothing on the Comstock is more plainly proved than this. Indeed if we attempt to learn by *a priori* reasoning what should be the constitution of a lenticular body of quartz, 200, 300, or 400 feet thick in the centre, and thinning on all sides until it runs out in a few seams interleaved in propylite, we reach the conclusion that such a mass was not formed by the opening of a crevice, but by the substitution of silica for the original rock, in some situation where the mother rock was peculiarly exposed to the action of quartz-bearing waters. It is not the phenomenon of deposition but of *substitution* that we have to deal with in such circumstances.

The theory of crevice-filling in a wide vein kept open by huge masses of country rock fallen from the hanging wall, which has been the accepted explanation of the phenomena of this lode for fifteen years, cannot be maintained. Crevices undoubtedly pre-existed as a necessity to the introduction of the siliceous waters; but they may have been extremely insignificant in section, perhaps no more than a mere separation of two layers along their line of contact. The vast thickness of some of these deposits, nearly 300 feet in cross section, and their position, imbedded in rocks that show no sign of a fissure in any direction about them, prove that substitution has done so much that it is not a violent supposition to ascribe the whole work to it.

Through the small crevices opened between the strata, as described, rose, during the andesitic period, currents of silica-bearing waters. That this took place while the andesite still lay upon the surface is assumed on the ground that in no other way can the almost total disappearance of its vast mass be accounted for. The removal of the rock was not accomplished merely by mechanical degradation of the surface, the much more powerful cause of chemical decomposition being probably the main agent in action. This decomposition was the ordinary process of kaolinization in which the andesite with about forty per cent of base and sixty per cent of silica, is transformed to clay, which, if it had the composition of existing Comstock west clay, had about the same proportion of silica, but also contained five or six per cent of water. The net results of alteration may probably be expressed as equal to the addition of about six per cent of silica; and this could be accomplished easily under the known conditions of hot siliceous water issuing from numerous parallel crevices several miles in length. The quantity of solfataric water must have been enormous, for on a rough computation it is probable that the *known* quartz seams, in the diorite and propylite represent together a mass of silica 500 feet thick and continuous with the strata.

This vast result of the mineral substitution which took place within the propylite and diorite, shows what the energy of decomposition—also mineral substitution—must have been in the andesite. This rock fissures readily, and the whole mass may have been in a lively state of alteration as well as of surface denudation. Therefore it is not surprising that very little andesite remains on the surface. It is true that King, whose survey of the surface was very complete, remarks upon the singular preservation of the andesite unaltered, though it lies upon propylite that is highly altered. This applies to the comparatively insignificant remnants of the great sheet. It is quite conceivable that an alteration which depended on the presence of hot siliceous waters should cease entirely with the cessation of their emission, and that an alteration-product so readily removed as clay should be completely swept away by ordinary atmospheric erosion, leaving the still unaltered rock in its natural exposure. As to the alteration of the propylite which at the surface seemed to be small within 600 feet of the lode, and so great beyond that limit, it is sufficient to say that the records of the only mining work which has penetrated this propylite mass in depth, the Sutro Tunnel, do not bear out the lesson of the surface observations. Within 1000 or 2000 feet of the lode the propylite was found to be decomposed, and the weekly record of progress made in the tunnel proves the fact, for it fell off so much that the works on the lode were not reached until some months after the expected time. East of that limit, or beyond 1000 or 2000 feet, the propylite presented the usual alternations of hard rock with occasional soft seams and andesite dykes. Underground the conditions were precisely the opposite from those which the surface exhibited ; and this fact indicates that the decomposition of the present propylite surface has been the work of atmospheric agencies and not of the siliceous waters which are assumed to have undermined the andesite.

The origin of these solfataric waters is obscure on the Comstock as it is elsewhere ; but as this discussion proceeds it will be seen that some novel conditions are brought within view through which it is possible that even this knotty problem may receive some elucidation whenever this wonderful region obtains the careful and continuous attention it deserves.

At present there are but two established facts governing this part of the subject. One is that each quartz body sensibly declines, and seems to totally disappear in depth. It is impossible to say that these masses are entirely isolated and not connected with any seam in depth, however small ; but it is true that the keen observation of the miners has not developed any such leader to ore. Indeed the fact that these quartz bodies occupy the place of propylite strata which once formed the summits of domes or ridges indicates that they should end almost completely in the trough below the dome. There the strata, instead of opening to receive the waters, would be strongly pressed together and more capable of excluding water than in their original condition. The Jacket quartz was observed to dwindle down from its great thickness of 300 feet to a few insignificant seams, lying near the black dyke, and the position of this lower edge of the quartz confirms another observation of a much more general character. That is, that a continuous, or nearly continuous vein does exist in connection with the black dyke. The origin and action of this vein will now be considered.

THE SOLFATARIC CHANNEL.

Not only the black dyke of the Comstock, but also the Justice dyke is almost everywhere accompanied by a thin vein of quartz, and it is a fact noticed in the diorite of the McKibben Tunnel and in the far distant propylite of the Sutro Tunnel, that a quartz body is always accompanied by an andesite dyke. The converse proposition is not true, for there are many dykes that have no quartz body, not even a thin dyke vein, while there are some that have a thin seam on the dyke but no great body near them.

From these facts I conclude that the main channel, continuous in depth, of the siliceous waters was that mass of propylite, a few feet in thickness, which lies next the dyke and was baked and fissured by its heat. There is no evidence that a vein ever opened in these rocks below the depth of 1000 feet from the present surface after the filling of the dykes, and when the dyke fissures were filled, their solidified contents behaved precisely like strata, to which their bedded condition, indeed, gave them the closest correspondence. In the squeezing of the rocks under the confining cap of andesite they have acted precisely like so many layers of propylite, and there is no sign that they have ever stood as rigid masses over which the other members of the series moved and left a narrow void. But the few feet of rock shattered by the heat of the dyke and probably accompanying it to great depths, afford a continuous channel for the passage of waters, and the existence of a thin vein against all dykes accompanied by quartz, and even against many which have no quartz masses near them, show that it was usually taken advantage of.

This dyke vein is distinguishable almost everywhere in the Comstock mines and its section at one point (going eastward) was as follows:

Dyke, hard.
4 to 9 inches soft black dyke.
4 to 9 inches hard, compact quartz.
18 inches decomposed propylite.
14 inches compact quartz.
8 feet fissile quartz.

This was a point where the dyke vein ran into the lower edge of a quartz body, which on higher levels was of great thickness and widely removed from the dyke along a portion of its strike. Elsewhere the dyke vein is sometimes very thin, and not infrequently disappears altogther in places.

The siliceous waters rising through these few feet of shattered propylite established the dyke vein by the progress of substituting silica for the angular fragments of propylite and also made their way into the system of partings between the strata, the entrance being effected in the troughs surrounding the domes. It has been pointed out that every one of the quartz bodies has a curved head, the curvature being toward the dyke. In many cases, perhaps in all, the quartz body is absolutely in contact with the dyke at some point. It is so for hundreds of feet in the Jacket body and for lesser distances in the Consolidated Virginia, Crown Point, and Justice. But the arrangement of the curved end of the quartz mass is such that the original seams in which its formation commenced pointed straight for the dyke, and it is quite possible that every large quartz body is connected with the dyke vein by a seam of quartz too small to be worth economical exploration.

The waters, then, filtered through the fissured propylite, flanking the dyke, and thence found access to small seams opened between the strata in those places where the straightening out of curves concentric to each other had forced the outer strata to arch themselves slightly on the inner layers. Then commenced the deposition of silica in the crevices under conditions which have left no distinguishing traces, but which may have been slower movement, reduced pressure and perhaps separation of carbonic anhydride which the mine waters, also faintly siliceous, still contain. The layers of propylite would be attacked simultaneously on both sides, the siliceous waters forming the most powerful solvent to which felspathic rocks can be subjected. The alumina received an addition of silica and water sufficient to transform it to kaolin, and the lode exhibits the method of the process. It is a fact that wherever the process of vein-making was interrupted and left in *statu quo* for our inspection (as in the case of a horse) a coating of clay is found upon the half-dissolved rock. In the Comstock this coating is always on the east side of a horse, that being the uppermost surface in its inclined position. Sometimes clay is found in the opposite side of the horse also, but it is uniformly found on the west wall both of the quartz bodies and also of those portions of them which abut on masses of propylite enclosed in the quartz. The existence of clay seams in the quartz is explainable by considering them as the last remnants of sheets of propylite which have been almost entirely removed by substitution. These clays are quite irregular and non-continuous and have always been puzzles both to miner and geologist.

When we consider that this process of substitution was continuously progressing from a great number of surfaces, that each of the propylite layers was attacked from two sides, and that the surfaces covered by the siliceous waters were very great in extent, and the time of the action was long continued, the vast dimensions of the quartz masses will not be a matter of surprise.

Beginning in the curved portions of the quartz, where the arching of the strata opened the partings between them, the waters would penetrate to great distances between the layers in neighboring portions of the formation, and the signs of this gradual extension of their action are seen in the immense length of the quartz bodies, combined with diminishing thickness toward the circumference. The water penetrated even the partings of the strata on the crest of the domes, where they were most firmly pressed together by the thrust against the andesite cap. But some of these bodies, the Crown Point-Belcher and the Justice, for instance, show a sudden thinning out at a certain distance from the curved end, and the indications are that the penetration of the waters into the succeeding 600 or 700 feet of propylite was slow. The greatest work of substitution was accomplished in those places where the strata had been thrown slightly apart or crushed by the pressure.

It is believed that every observed phenomenon of the quartz bodies has now been accounted for. The number of these masses is very great. At least two important lines of them in the diorite, one at the contact of the diorite and propylite, and probably four or five others in the Sutro Tunnel, besides others on a somewhat different strike, in the Justice and Lady Bryan, are known. Indeed it is not improbable that if the diorite were more thoroughly explored, the whole number of lines along which the dynamic movements have acted and the process of substitution has taken place energetically might be increased to a dozen, and in addition the rocks contain a great number of thin seams. But confining ourselves to those which are known, their magnitude and their length wherever the latter has been tested, point to an immense outpouring of vein waters during the first quartz period. The known amount of quartz in the Comstock lode alone must be more than 100,000,000 and perhaps 200,000,000 tons, of which much the greater part is left in place, being too poor to be workable. About 7,000,000 tons of ore have been removed. Others of the parallel quartz lodes do not appear to fall behind the Comstock in size, though they do in tenure. To put the amount of silica introduced into these rocks at 1,000,000,000 tons is probably to keep within fair bounds.

The small proportion of silica which water under ordinary conditions will dissolve makes this quantity of quartz the representative of vast floods of water, the effect of which upon the andesite cap would be very great, however much time is allowed for its action. Among the extremely few errors which Von Richthofen made in the discernment of local conditions, was the observation that the erosion of this region had not been great. Both Mr. King and I have come to the contrary conclusion, and the huge quantity of hot waters which the amount of silica in these rocks represents supplies a sufficient source for the decomposition and erosion which is now discerned.

The story of the Comstock as a quartz lode is now complete. It has the reputation of being a true fissure vein of the very first magnitude ; but there is no sign of a fissure, and even the word *vein* must take on a new significance to cover the extraordinary deposits of this region. With the disappearance of the fissure depart also the attendant phenomena, the horses, the crevice filling, igneous injection, gaseous emanation, and the tremendous boiling and bubbling which have been looked upon as such fitting concomitants to the making of so great a " vein."

Now that these views upon the dynamic mrovements of the lode region are so fully before the reader, it may be well to turn back in this narrative and recall the grounds on which some of the conclusions are based.

While the great spread and thickness of the andesite overflows are indicated by the existence of dykes in the highest crest of Mount Davidson (not in its *peak*, however), and overflows at an altitude but little lower, this indication is confirmed, if the explanation here given of the origin of the quartz bodies is accepted, by the fact that those bodies, immense in extent, are found in the diorite of Mount Davidson as well as in the propylite. If they began in the upward pressure of the stratified diorite against an andesite cap, that cap must have had a considerable thickness over the main mass of Davidson, the highest of the mountains.

The stratification of the diorite, which is not so well proved as that of the propylite, owing to the small number of openings examined in it, is also a necessary deduction from the perfect parallelism of its history and that of the propylite, the stratification of which is considered to be indisputable. Its quartzes had their origin in the parting of strata under side pressure as did those of the propylite.

From what has been said of the insignificant dimensions of the first crevices and the formation of quartz bodies by substitution in rock layers, rather than by deposition upon the walls of a fissure, it will be seen that I do not acknowledge the existence of the "horses in the vein" which have for years been considered to form such a prominent feature of the Comstock. This is one of the ideas regarding the great lode which emanated from its first explorer, Von Richthofen, whose examination was confined to the uppermost 500 feet, where nearness to the surface modified the action and atmospheric decomposition has masked the true conditions. He supposed the lode to be a fissure vein, and that the great masses of propylite were horses enclosed in quartz. These horses, he conceived, were fragments that had broken away from the hanging wall and fallen into the vast chasm of the fissure, which he thought was "about 100 to 120 feet in width." He expected that places might be encountered where the vein filling would have a brecciated structure, consisting of small propylite fragments enclosed in quartz. Such discoveries are common in mines of lead, copper, and zinc, and in the Comstock also, but they indicate there a condition of arrested substitution and not of a loosely piled mass of fragments with its interstices filled in with quartz.

These views of Von Richthofen have survived the immense exploration and the somewhat spasmodic scientific study of this lode during thirteen years. The opening of a vast crevice and the falling in of tremendous portions of the east or hanging wall, are still matters of faith with the miners and with geologists. But I have been unable to agree in such conclusions. There are no occurrences of horses enclosed in quartz, such horses being part of the hanging wall. The structure is of the contrary kind, there being masses of quartz lying in propylite, and the presence of sheets of the latter rock only shows that the process of substitution was not long enough continued to replace the erupted rock completely. No one who is conversant with the shape of these propylite (and diorite) horses, as it has now been disclosed by long continued working, would describe them as fragments of the hanging wall. They have immense length and height and the least possible thickness. They may be 1000 feet square and not 20 feet thick, as in the black dyke. Masses of such dimensions never fell, or could fall, without breaking in pieces. In fact they never hung over a chasm, but from the day they were laid down as successive outflows of lava to the hour the miner uncovered them with his pick, they have never for an instant been unsupported over any considerable area, or by a wide chasm. The "fissure" beneath them may not have been large enough to admit the hand, and its area at any one time may have been not half that of the existing horse.

Some years ago a human skull encrusted with silver ores was found in some neighboring diggings, and was commonly reported to have come from the true mine workings. The local editor is said to have drawn a striking picture of the unfortunate specimen of pre-historic man who, as he peeped over the edge of the vast chasm, boiling like a cauldron, lost his senses from the stupefying influence of chlorine, fluorine, sulphur, carbonic anhydride, and other gases, and tumbled in! But though this entrance to the infernal regions was supposed to be several hundred feet wide, and well filled with horses, the fact is that the original fissures from which the Comstock has been formed were most probably no larger, individually, than the existing fissure at Steamboat Springs; that is to say, a few inches in width. The most pre-historic of men could hardly have tumbled into any of them.

With this disappearance of a great fissure must pass also all the deductions which have been based on such a state of things. The ore bodies do not occupy swells in a vein which were caused by the movement of the walls bringing two opposite concavities into juxtaposition. Such movements are discernible in the black dyke, which can be continuously followed through a succession of such nips and swells; but the shape of the quartz bodies forbids such a supposition as applied to them. That such misconceptions should maintain their ground is easily explainable by the great dimensions of the lode and the extent of the works, both of them making study formidable and masking phenomena which would be plainly apparent on a smaller scale.

CHAPTER V.

FORMATION OF THE ORE QUARTZ.

Of the four great dynamic periods in the history of the Comstock, three have now been examined, those of the diorite, the propylite, and the andesite. That of the trachyte remains, but before entering upon its discussion attention is called to the fact which gives this closing period its important significance, not only to the Comstock, but perhaps also to a large class of silver and gold deposits in the west.

The reader may have noticed that though the formation of quartz bodies has been described, nothing has yet been said about the introduction of silver or gold. It is probable that the andesitic period passed without the production of ore, though the greater portion of the quartz owes its existence to this period. The reason for this conclusion is that the metals are not disseminated through the quartz, but are confined to particular portions of it. This could hardly be the case if the siliceous waters had also been argentiferous through the whole period of their action. In that case there might have been concentration of the noble metals in given portions of the lode with relatively poor sections, mainly of country rock, elsewhere; but there could hardly be such entire exclusion of them as we now find from vast masses of quartz, both solid and mixed with porphyrite. There is silver and gold everywhere, the rock assaying *something*, a half dollar or a few cents a ton in almost any situation. But these bodies have been explored for 300 feet thickness on some levels without finding so much as a handful of ore that would "go" ten dollars a ton, while within 100 or 200 feet a level would exist that was filled with rock which with all its local fluctuations in value would supply thousands of tons of $50 and $60 ore.

Such violent changes could hardly exist in rocks of uniform composition derived from solution if the mother waters were metalliferous from the beginning. And as a reasonable explanation of the phenomenon has been found, I have arrived at the conclusion that the filling of the Comstock occupied two distinct periods, a siliceous and a siliceous-argentiferous one, separated by formidable geological events which are now to be described. The quartz of the two periods is distinguished solely by its content of gold and silver. The barren bodies contain sulphides of iron, lead, and copper, with zinc occasionally, and their alteration-products, in quite as great quantities as the ore bodies; but silver and gold are present in them in such small proportions that they can be fully accounted for on the hypothesis of subsequent or accidental infiltration. Though already in existence, these masses of silica did not offer the physical conditions requisite for the introduction of the precious metals. Perhaps an exception should be made in the case of gold, which has been quite extensively mined from quartz that apparently belongs to this siliceous epoch.

During the period of chemical activity to which the Comstock region owes the establishment of so many parallel lines of quartz deposits, the forces at work appear to have been as quiet in action as their results are vast. The deposition of the quartz and the removal of the huge mass of andesite from the surface may have been accomplished by agencies working so gently that a geologist might have passed over the surface at the time without suspecting what great operations were in progress beneath his feet. But this period of calm was followed by another of intense dynamic movement, the fourth and last which will be considered in the history of the district.

Great crevices were again opened in the rocks, or rather between them probably, as in the andesitic period. A new material appeared, trachyte, and its quantity was about as great as that of its immediate predecessor, for it was poured out in a flood that rose high upon the Davidson range, though the nearest source of the eruption was a mile and a half to the east. All of the new fissures lie far to the eastward of the diorite, away from the main line of exploration, and the character of the eruptions, whether numerous or few in number but great in extent, is unknown, though the Sutro Tunnel affords an invaluable means of studying this portion of the formation.

The evident facts about the trachyte are that it now forms hills rising to a height of about 6500 feet above the sea level, and from 1200 to 1300 feet above the sloping propylite surface on which it rests. The small patches of this rock which are scattered over the propylite and rise upon Cedar Hill (the peak immediately north of Mount Davidson) reach an altitude of about 6300 feet, which indicates a minimum erosion in the longitudinal valley of at least 1300 feet. The probability that all this ground was covered by the trachyte flow has not been previously advanced; but Mr. King regarded these patches as parts of a sheeted overflow, as there is no evidence of a dyke in their neighborhood. He seems to have considered this sheet as distinct from the great mass of this rock in the eastern hills; but when it is remembered that the trachyte appeared as a surface overflow, and that it now forms peaks 1300 feet high, it is evident that the limits of the overflow must be sought for away from the immediate neighborhood of its greatest mass. The possibility that it could have occupied a valley, or the eastern front of an andesite elevation, is removed by the occurrence of its outlying remnants in direct superposition upon the propylite, a fact which establishes the previous removal of the andesite. It must have had great extent and thickness, its present dimensions being determined by erosion.

The erosion is less than that in the andesitic period, partly because the main body of the latter rock lay further to the eastward, and therefore away from the decomposing siliceous waters, and partly because the solfataric agents were diminishing in force.

In considering the effect of the trachytic eruption upon the Comstock lode it is necessary to bear in mind two facts: first that the newly arrived rock was a mass of such weight as to form under any circumstances a geological factor of the first importance; second, that this great weight was deposited in such a position that its main mass lies two to three miles from the lode and *on its dip.* On the side away from the lode these trachyte hills overlook the valley of the Carson river, five miles or more in width. Here on the valley side the hills are quite precipitous, and there can be no doubt that the trachyte streams originally extended far over the Carson on the east as their scattered remnants prove that they covered the Comstock ground to the westward. The river erosion has cut entirely through the mass and deeply into the propylite on which it rests, the lower part of the bluffs being composed of the earlier rock.

There is every indication that the hills which now rise so abruptly more than 1200 feet above the propylite are but the remnant of a great trachyte sheet probably towards 2000 feet thick at the deepest portion and with a minimum width of six miles. It extends through the whole Comstock region opposite

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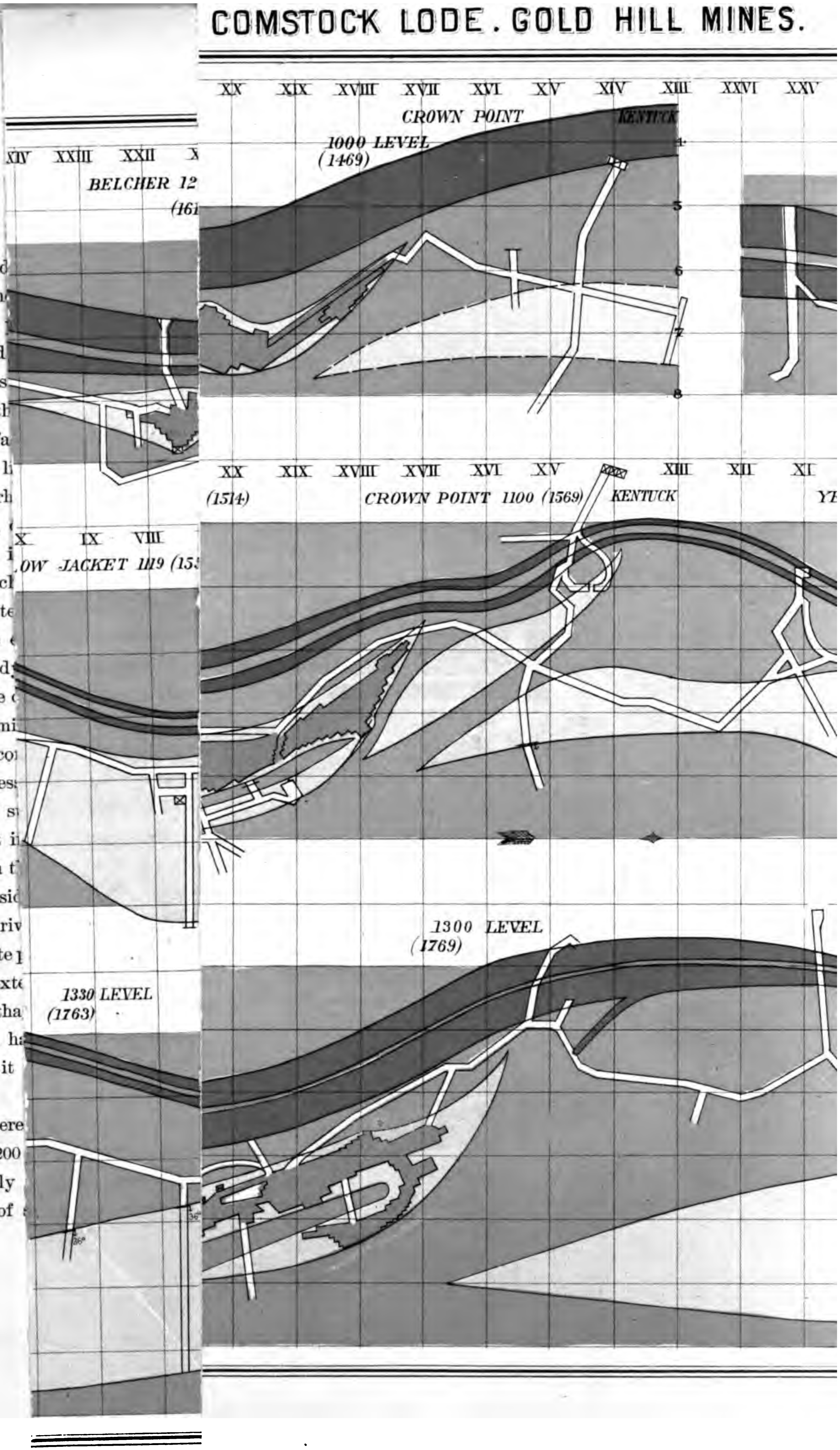
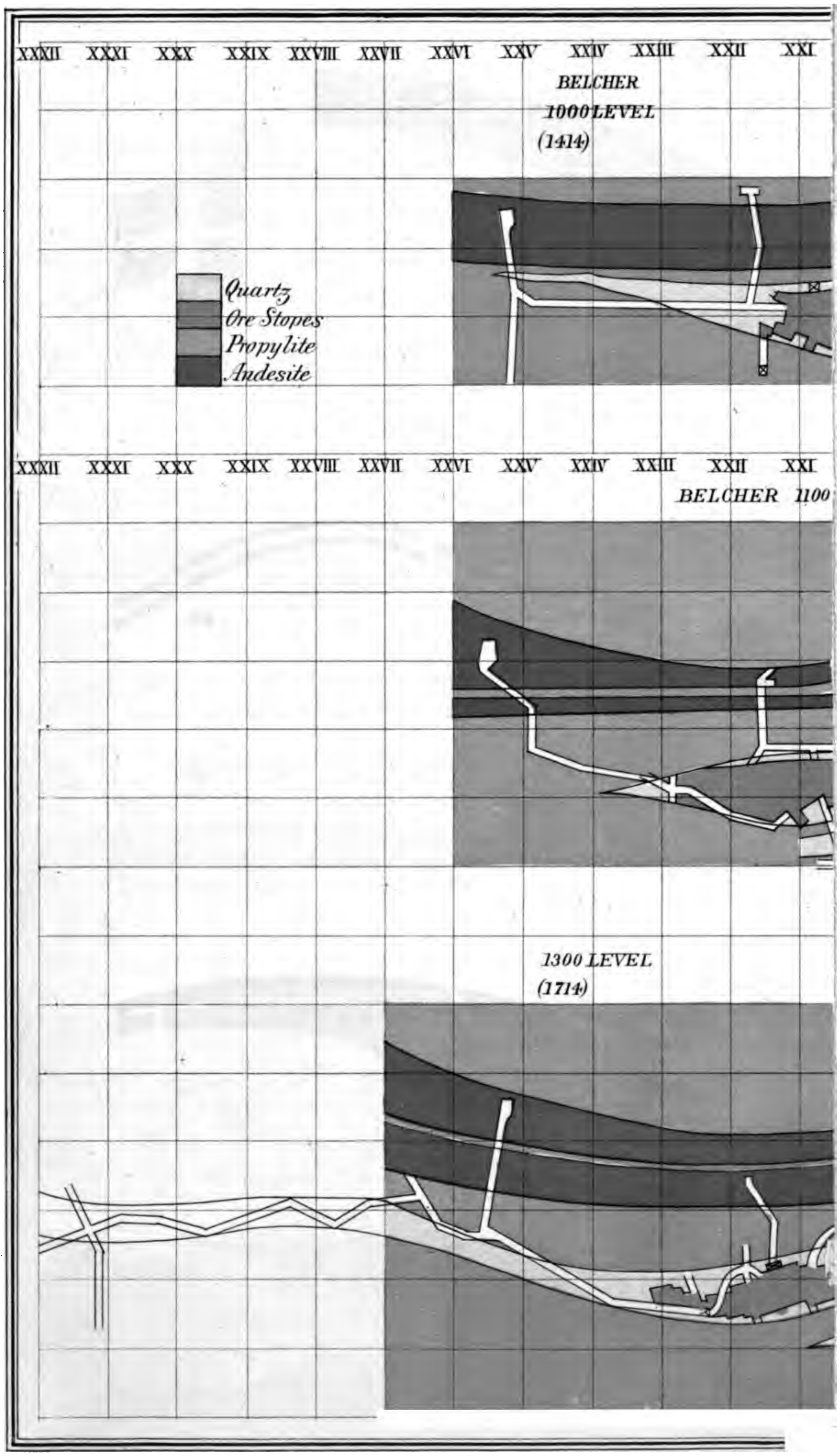


COMSTOCK LODE. GOLD HILL MINES.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the lode, and was amply sufficient to produce all the effects which will be ascribed to it.

Lying on the dip of the rocks the trachyte seems to have acted entirely by its weight. Even if the north and south pressure continued, the existence of large bodies of clay in the rocks from the action of the siliceous waters would prevent the repetition of the peculiar action which took place under the andesite cap. This *a priori* conclusion is confirmed by the character of the one dynamic result which the trachyte produced upon the quartz bodies. Hitherto the description given has been confined to the quartz bodies without reference to their metallic contents; but it is now necessary to consider the position of the bonanzas as distinguished from the barren bodies of quartz.

It seems to be the general impression that these two kinds of deposit are physically as well as economically distinct. They are commonly spoken of as if the barren body were a separate entity from the ore body, but that is not the case. Almost any of the known bonanzas may be examined to prove that these two kinds of quartz are not separate masses, but that the rich quartz merely forms one portion of a great ledge which, in addition to the ore, contains also an extensive and thick mass of unproductive rock.

The reader will find this relation of the two classes of ledge matter well illustrated in the great Crown Point-Belcher body shown in Plates I., II. and III.

Quartz was found above the 900 foot level of the Crown Point; but ore did not make its appearance in this quartz mass until that depth was reached. It continued to a point about half way below the 1500 level where it gave out, but the quartz continued down to the 1700 level and beyond it. On the 1600 level its thickness was still 75 to 100 feet, and on the 1700 level it was 50 to 75 feet thick. Below that point it continued to diminish in size, but is still 40 feet thick in the Belcher 1900. There were ore bodies in the Crown Point above the 900 level, but it is not probable that they belonged to the same quartz sheet. They appear to have been enclosed in a mass of quartz which overlapped this, and which was perhaps the same sheet that held the Jacket ore on the same levels.

This continuity of the rich and barren quartz is fully proved in the Jacket body, probably the most conclusive example presented in the lode. Above the

1028 level the Jacket had a magnificent ore body which had continued from the 290 foot level in the north shaft. This suddenly gave out at that point, and on the 1119 level, where this quartz is nearly 300 feet thick, and quite free from propylite, it failed to yield even one ton of ore in spite of very thorough exploration. Continuing on down it passes the 1330, the 1432, and the 1531 levels in undiminished magnitude, though its character changes at the last-named depth to a system of interleaved quartz and propylite sheets. Below this the thickness of the mass diminishes rather rapidly and the quartz appears to withdraw toward the black dyke, so that on the 2032 level the quartz body is quite thin and close to the dyke. All this is barren, and in the whole mass the unproductive quartz very much exceeds the productive in amount. It is known throughout the Comstock region as the Jacket Barren Body, but it is nowise separable from the Jacket ore quartz except by the absence of metallic contents. Physically the two form a unit. The ore body disappeared in depth in a series of wedges running down into the barren quartz, and the reason for the non-continuance of metal has been a mystery ever since.

POSITION OF THE BONANZAS.

But while there is no separation of the two kinds of quartz, there is a marked difference in their position, which will be evident upon looking at the section of the Jacket mine, Plate III. This section above the 800 level is taken from Mr. King's report of the Fortieth Parallel Survey, and a part has been added by Messrs. James & Wrinkle, surveyors. None of the ore ground was open to me, my work commencing on the 1119 level, and continuing to the 2200.

The only difference discernible between the rich and the barren quartz is that the former lies in a highly inclined portion of the lode, while the latter occupies the flatter portions. This difference exists in all the ore bodies examined, being invariably made out when the position of the rich ground could be compared with that of the barren sections, and this mode of occurrence is sufficient to unlock the mystery which has enfolded so long the occurrence of the Comstock bonanzas.

When a continuous quartz body of great extent is found to carry ore only in those portions which are most highly inclined, while the flatter portions are not in the slightest degree deficient in quartz, we may safely rely upon two conclusions:

First, The silica did not always carry the metal.

Second, After the quartz had been deposited, the strata were reopened by some force which only affected the steeper portions, and at the same time the metallic contents of the lode were introduced.

When we seek for the agent which produced these results in the Comstock, we find there is but one great dynamic event subsequent to the first appearance of quartz. This is the eruption of trachyte and deposition of its immense mass upon the hanging wall of the lode. In that position its huge weight forced the inclined strata to move upon each other. The hanging wall slid upon the quartz masses, pressing closer together those parts which are flat, and drawing the walls apart where they were more steeply inclined. This action takes place whenever the hanging wall of a vein moves. That such a movement has taken place in the Comstock is not a deduction from the presence of the trachyte, but from the constant occurrence of ore in the steeper parts *only* of the quartz bodies. Had the contrary action taken place, and the foot wall moved downward, the more level parts of the quartz would have been opened to receive the ore, and that would have been a remarkably fortunate occurrence for the Yellow Jacket, which would then have had one of the largest bonanzas ever known.

A very striking exhibition of the important influence which the degree of dip has exerted on the fortunes of the different portions of the lode is found in the Virginia mines. In this northern section there are wedge-shaped masses of propylite lying in the lode, edge downward. They have quartz on both sides, and the dimensions of one of them are so great—being from 100 to 250 (average 125) feet thick and 1100 feet long—that the two bodies of quartz into which it separates the lode were at first considered to be two separate veins and were claimed and worked as the Virginia and the Comstock lodes, the former being on the west, and the latter on the east of the propylite dividing them. The dip of the Virginia ledge was eastward, but the dip of the Comstock was at first toward the west, and the eastern dip of the lode was unsuspected until the explorations in the Ophir had reached a depth of about 400 feet. Only one of these veins yielded ore, the west or Virginia body proving to be barren, while the Comstock, or east body contained the ore channel.

Hitherto this anomaly of a barren and a productive quartz body on the same level and both of great magnitude, has remained a mystery; but it is entirely explainable by the facts now brought forward. The west or Virginia ledge belongs to the andesitic, or non-argentiferous, quartz period. It has the regular eastern dip of the strata. The Comstock or east vein is a product of the trachytic or argentiferous quartz period. The weight of trachyte has broken the propylite at this particular point instead of sliding it over the already formed Virginia ledge. The new crevice, a true fissure vein, was opened in the hanging wall, and as its tendency would be to take the shortest line after leaving the lode, it would necessarily have a western dip, that being the perpendicular to the east dip of the eroded surface. Argentiferous quartz filled the new crevice instead of enriching the mass of the old quartz body. The filling of this eastern vein with quartz as well as metallic minerals and the existence of a noticeable difference in the physical condition of barren and argentiferous quartz, are indications that the trachytic period was not one of metallic impregnation merely, but that it was a second period of siliceous deposition in which a new element was introduced.

This deduction is opposed by the fact that small masses of propylite or diorite or any other country rock, enclosed in the quartz, may be as rich in metal as the quartz. In such cases the igneous rock is altered from its original state, but not so highly altered as to lose its firmness. The ore of the Comstock is not quartz, as it is so commonly reported to be; but a mixture of quartz with diorite, porphyrite, quartz porphyrite, porphyritic breccia, or any other rock that happened to be locally subjected to the action of the metalliferous solution. The miners know this perfectly, and regard a mixture of quartz with country rock with more favor than they do unmixed silica.

This impregnation of the country rock whenever it is found in the ore channel is probably an additional proof that the metals were introduced in solution, though it is not incompatible with deposition from the gaseous state. Its most important significance is in its bearing on the question of the siliceous or non-siliceous composition of the waters in this period. The deposition of metal in the porphyrite may be considered a fact in support of the negative; but the other evidence is thought to contradict this single fact overwhelmingly.

Further, Mr. King has shown that the horses of the lode contain much more silica than the propylite of the country rock.

There is a noticeable difference between the character of the quartz in the rich and the barren portions. The former is a sand in texture, much of it as fine as the sand of an hour-glass, coherent when in mass, but capable of comminution by rubbing between the fingers. It is known as "sugar-quartz," and very much resembles crushed white sugar or table salt. The grains are remarkable in *never* being crystalline, the microscope not revealing one crystal in millions of the particles. Many of the bonanzas have been composed of this quartz, and among these the Consolidated Virginia and California, the most valuable of all. The whole of this mass is not a uniformly crumbling powder, there being propylite in it and also fragments of harder quartz and masses of ore so rich that the metallic contents consolidate the sand. But the crumbling sugar-quartz forms very much the largest part of every car-load of ore, and in milling, a stamp which elsewhere cannot crush more than one and three-quarters to two and a half tons of rock is able to pass five tons daily of this ore through the sieves.

The barren quartz is of very different appearance and texture. It is almost uniformly hard, and often shows a crystalline arrangement, though crystals are not common even in vugs. While the sugar-quartz is milky white, and sometimes dazzling, the barren quartz is clear gray and grayish white. This consolidation of the barren quartz adds some confirmation to the settling down of the hanging wall upon the flatter portions of the quartz, which is so clearly indicated by other circumstances.

The metalliferous quartz has not always been sugar-quartz, the ore of the upper levels being hard and quite similar to barren quartz except in its proportion of gold and silver. In the absence of known special occurrences which might have caused this difference at the time of deposition, it may be attributed to the action of atmospheric waters producing re-solution and re-deposition of the silica, and cementing the originally loose particles into a solid mass. All of this hard ore quartz is within the 600 or 800 feet of depth which may be included within the limits of ready surface drainage. Below that area the ore quartz has been uniformly loose except where consolidated by an extremely large proportion of metallic minerals, or the local secondary deposition of silica.

Even the barren quartz in the lower levels is for the most part less hard than it was near the surface.

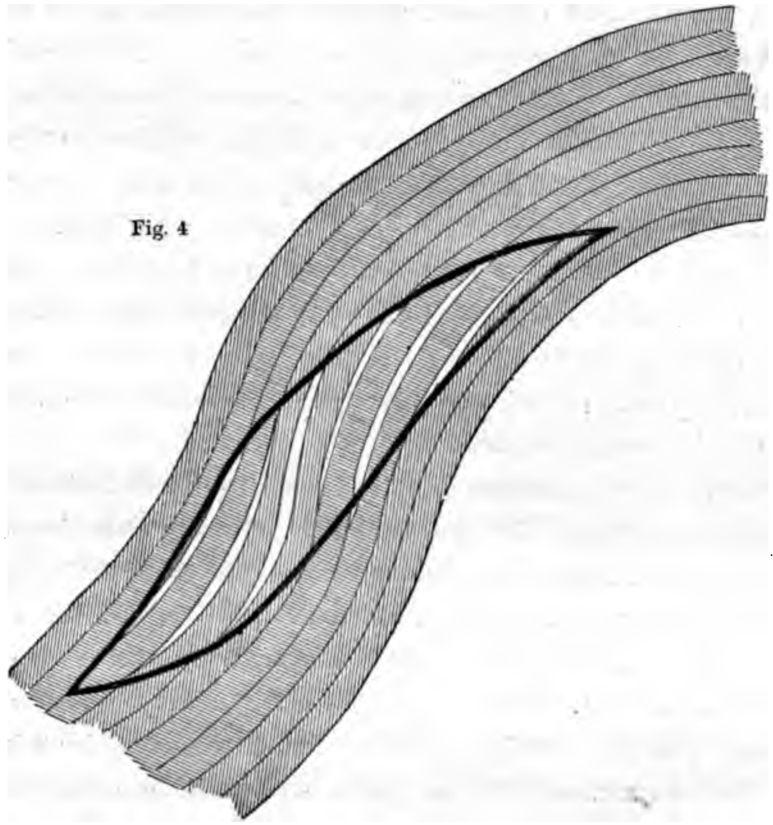
A singular example of this process of re-solution and re-deposition of the silica was afforded by the upper levels of the Gould & Curry mine. Here, says King, p. 73, "the easternmost zone of the (ore) body was highly crushed, very richly charged with silver ores, and very easy to mine. After this had been stoped out to a considerable extent, it was found that the next zone, which lay in immediate contact with it, was composed of large blocks showing no ore upon their outside, but extremely rich in the interior. These fragments, often weighing half a ton, showed not the slightest trace of silver minerals for the first two or three inches from the surface, but the entire middle was one densely charged mass of rich ore." West of that again was a zone of poorer rock which has since been worked.

The cause of this peculiar deposition of rich ore disposed in separate masses behind a mask of barren silica, must be sought for in the process of re-solution of the quartz by atmospheric (or possibly by later solfataric) waters. The original ore seam shrank away and cracked, and into the crevices new silica, dissolved from the lode itself, was carried and covered the rich fragments with their barren coating of quartz.

The difference in the physical character of the quartz deposited in the two great chemical periods, the non-argentiferous and the argentiferous, is hardly strong enough to indicate whether there are quartz bodies in the lower part of the lode which are to be referred entirely to one or the other of these periods. Such a deduction has already been made for the Comstock as distinguished from the "Virginia vein" at the surface in the northern portion of the lode, but that was founded solely on the west dip of the former, this western inclination being taken as a sign that the easternmost of these two channels was formed entirely during the ore period. If any bodies are found which with a dip of uniform angle contain none but argentiferous sugar-quartz, it may be possible to assign them entirely to the later period. Another indication of some moment is the richness of the ore. Where an old body of barren quartz has been infiltrated with metalliferous waters of given strength the result will be a large body of low grade ore, while the same waters filling up a new crevice would produce a quartz of very much richer character. Perhaps the wonderful wealth of the highest portions of the lode was partly due to that cause, as well as to re-solution of the metallic mineral by surface waters. A similar singleness of origin may possibly have produced the unusual wealth of the Consolidated Virginia and California bonanzas, and the shape of these bodies is not opposed to this supposition. They have the usual lenticular form, and the four bodies composing them, which are really a geological unit, taken together faithfully repeat the usual curved form of the Comstock bonanzas.

The Consolidated Virginia body, for instance, is not only a concavo-convex lens in its cross section, but it is a lens of which the convex side is almost a cone. With a length of 450 feet on the 1500 level, as the still unfinished work of extraction exhibited it, the mass had a width of about 200 feet. This does not include the California body which is separated from the former by a horse.

Fig. 4



SUBSTITUTED MASS.

Ideal section of folded strata with position of ore body on the lower side of a dome.

Such a mass might be formed on the lower side of a dome, inclining with the diorite uplift, and having its strata pressed down by a heavy weight. While the north and south pressure acting under the andesite cap as previously described has produced quartz bodies in the east and west troughs between the domes, this vertical pressure would, by a similar sliding of the strata, open crevices or completely shatter the strata on the lower side of the domes, where new quartz bodies would be laid down by a repetition of the substitution process. These newer bodies might be continuous with the older or they might be distinct. If there had been previous opening of the strata in this position the ore would be rich or poor according to the proportion of new to old quartz; but it is quite conceivable that the formation of some of these bodies should be entirely included within the argentiferous period, in which case the resulting quartz would be very rich. The position of bodies formed in this way, whether barren or metalliferous, is shown in the accompanying cut, Fig. 4.

The figure shows that when an ore mass is formed in this way the layers of the country rock will be crossed one after the other in the direction of their dip. None of the quartzes observed on the Comstock showed this proof of their origin; but it was very clearly exhibited in the Justice lode which will be fully described in another chapter.

Throughout the mines the ore quartz is usually found to lie in broad and long sheets in the centre of the quartz bodies. Usually there is poor quartz both east and west of them, excellent examples of the structure being found in many mines. Perhaps the best is that in the Belcher, mentioned by King, p. 43. There a quartz seam 61 feet thick was made up of five members, only one of which carried ore. The section, proceeding from the east, was: 3 feet clay; 20 feet mixed quartz and propylite reddened by iron oxide; 2 inches clay and sand; 30 feet quartz without propylite, but broken into irregular blocks; 3 inches black drusy quartz; 6 feet ore quartz also broken into blocks; 18 inches black quartz fragments and round water-pebbles; 4 feet white blocky quartz; clay. In the lower levels no instance of such marked separation is to be found, but the interposition of a sheet of ore between two leaves of barren quartz is common.

It is sometimes the case that the top of an ore body is formed by a thin seam of rich quartz, and the composite structure of rich and barren rock is found only in the thicker portions of the mass. In a similar way the ore may run out in a thin wedge penetrating a thick mass of barren, or very low grade quartz, as was the case in the Crown Point. Or the lower termination may consist of a series of wedges, lying in barren quartz, as in the Yellow Jacket. There are two cases known of an ore body abutting against a solid wall, and they have been cut off sometimes by a thin clay seam, with barren quartz beyond. The former was the case of the "west vein" in the old Jacket works, where the vein was followed to a depth of 400 feet with a west dip until it was cut squarely off by the west wall which has a very flat east dip at this point. It stands so near the shoulder at which the steeper dip begins that this west vein may be referred mainly to the trachytic period, and considered as a fracture opened in the propylite at a point where the dip was too flat for the hanging wall to slide down under the vertical pressure. This too is an instance of a rich seam enclosed between two poor ones, and it is also true that even the few quartz bodies which show some reason for assignment to the trachytic period alone all contain some barren quartz. The west vein of the Jacket lies against metamorphic strata, and it deserves to be mentioned that the Justice which occupies a similar position in its upper levels has at that point a slight west dip also, though the strata dip steeply to the eastward.

In discussing the non-argentiferous deposition of quartz, the thin layer of broken rock lying on the east side of the black dyke was pointed to as the probable channel of the siliceous waters. It appears to have performed the same service for the metalliferous solution, for it is nearly everywhere ore-bearing, and would be a valuable source of the metals if it were of greater dimensions. Its extreme thinness is the only circumstance which throws serious doubt upon its selection as the probable channel; but the entire absence of any other continuous opening, however small, and the constant relation which the quartz bodies bear to the dyke are strong testimony for the affirmative. Some unknown circumstance, or the baking of the rock by the heat of the dyke, may have protected the porphyrite from more extensive solution in the vicinity of the channel.

Attaining the old quartz bodies by this means, the argentiferous waters would saturate them and form rich deposits wherever the opening of the ground had left seams in the masses. Narrow streaks of pay ore, too small to be profitable, are found enclosed in thick masses of barren quartz, their position being vertical; that is to say, they occupy the same general dip with the main quartz, and do not cross it horizontally. The existence of these insignificant depositions of ore in the midst of an overwhelming mass of barren quartz is of itself evidence that they are not contemporaneous with the main body, and their position bears out the theory of dynamic movement which is given here.

The erosion produced by the waters of the trachytic period was much less in amount than that of the preceding period. A vast quantity of rock has been removed, very little of the western portion of the trachyte sheet being now in place. But in the eastern portion of the Comstock field, two miles from the lode, this rock still forms the massive hills already described. The position of this erosion may have an important significance in reference to the probability of finding ore in those quartz lodes which lie near these hills. If there is any correspondence between the amount of erosion at this time and the quantity of argentiferous waters, the eastern lodes, of which there are some massive ones, may have received less ore than the western, as there is less erosion in their neighborhood. Unfortunately, the geologist cannot offer the miner any guidance in this matter, but must look to practical explorations to solve the question.

CHAPTER VI.

DESCRIPTION OF THE MINES.

The Maps. Before entering upon an account of the several mines and the distribution of lode materials in them, it is necessary to explain the mode upon which the accompanying maps have been constructed. They are based upon the working maps of the mines made by Messrs. James & Wrinkle, surveyors to all the principal companies, to whom I am indebted for much assistance, given with the consent of the several superintendents. In these excellent maps the whole ground is marked off in squares of 100 feet each, and in order to fix with readiness the position of any point, the cross lines have been numbered in the accompanying sections on the following plan: each of the two principal portions of the ground, the Virginia and Gold Hill groups, has its own numbering, the zero line being taken in the Imperial mine between the quartzes of the two systems. From that point the Virginia lines are numbered from 0 upward going *north*, and the Gold Hill lines are numbered in the same way going *south*. This is for the east and west lines which mark the distances in the north and south direction.

The cross lines, running with the strike of the lode, and representing east and west distances, are numbered from a line running 100 feet west of the Eldorado croppings of the Gould & Curry. This is near the position of "Point A," the datum to which depths in the mines are referred when a common datum is used. The zero line being 100 feet west of this point, No. 1 falls in the line of these croppings.

By uniting these two series of numbers the position of any point in the whole line of mines can be indicated. Thus the most southerly point of the Consolidated Virginia Bonanza, where it was discovered, lies on the 61st line north, and between the 12th and 13th lines east of the two datum points respectively. Or it may be more exactly designated as 6100 feet north and 1275 feet east. The northern termination of the system of ore bodies to which that bonanza belongs is found on the 1600 level of the Ophir, on the 74th line north, and between the 17th and 18th lines east; or 7400 feet north and 1750 feet east. The series of four ore bodies in this system accordingly covers a length of 1300 feet on the strike of the lode, and makes a total easting of 475 feet. As the difference in height between the Consolidated Virginia 1200 and the Ophir 1600 is 503 feet, the average dip of the whole ore-bearing ground, without regard to its pitch, is nearly 71 degrees. This example shows how readily the Comstock system of mapping lends itself to rapid calculations.

The mode in which the geological facts observed have been exhibited on the maps also deserves some explanation.

The maps given with this memoir show horizontal and vertical sections of mines in Gold Hill and Virginia only, those of American Flat not being included on account of the impossibility of visiting them. Very little was accomplished in the Virginia group, where the only ore bodies in view were those of the Consolidated Virginia and California. Elsewhere all was dead work and two of the mines, Hale & Norcross, and Savage, were under water so deeply as to make their exploration extremely superficial. On this account the sections taken from the Virginia group are confined to the Consolidated Virginia and California ore bodies. Only in the Gold Hill group was the work of exploration thorough enough to permit the relation of neighboring quartz masses to be made out, and there the simple arrangement of the lode materials added greatly to the solution of the problem presented.

The dyke vein is not exhibited on any of the Comstock maps, though it was found at nearly every cutting through the dyke. But its dimensions would have to be greatly exaggerated in order to show it, and its presence over the whole surface of the dyke would have to be assumed. Still it should be borne in mind that this slight but important factor in the formation of the Comstock lode was constantly discovered by actual observation. In the Justice it is more prominent and is shown in the plates.

In compiling these maps no attempt has been made to exhibit the natural curvatures of the bounding lines, except in the horizontal plans of levels, where this method is almost enforced by the position of the significant points. But in the vertical sections the known points have been connected by straight lines, as this method was felt to offer the least enticements to unnecessary assumptions as to the form of the quartz and ore deposits. Whoever undertakes a survey of the Comstock will find that there is an almost irresistible tendency to the manufacture of regular crescents wherever it is necessary to supply portions of the lines. But he will also discover by careful examination that the forces which have formed the lode have almost invariably declined to follow this form in the lower part of the ground. Curvatures there are in fact, and many lines that are necessarily drawn as curves because the variations from that figure are difficult to make out. But all experience points to the danger and inaccuracy of such additions. The boundaries of the quartz, and even of the richest ore, are very often angular. Hardly ever do they compose a crescent.

The peculiar mode in which ore quartz advances into the propylite by a series of steps is well shown in the Consolidated Virginia ore body on the 1500 and 1550 levels. There the mass of ore seems to be made up of square blocks sometimes joined by their corners. In the small way the step-like line of the ore is a consequence of the mode of timbering adopted, which is in square sets about five feet long, six feet wide, and seven feet high. When ore is removed the irregular line of the wall is cut out sufficiently to admit a set, and where the line advances by an easy curve it will be marked on the stopes by a gradation of steps composed of one, two, or more sets at each step. But this artificial requirement cannot explain the deep squares shown on the 1500 level of the Consolidated Virginia, nor the square outlines of the west side of the same stopes on the 1550 level. Straight lines of 50 and 100 feet in length are found on those levels, and elsewhere in the same mine the rich ore is seen to be cut squarely off, without a taper. This is undoubtedly as artificial as the regular crescents which are so often exhibited on maps of these mines, and in working out the ore of lower grade these square terminations will no doubt be resolved into more tapering forms. But it is true that in many cases the lines of the deposits are found to be as straight for considerable distances as they are ever found in nature.

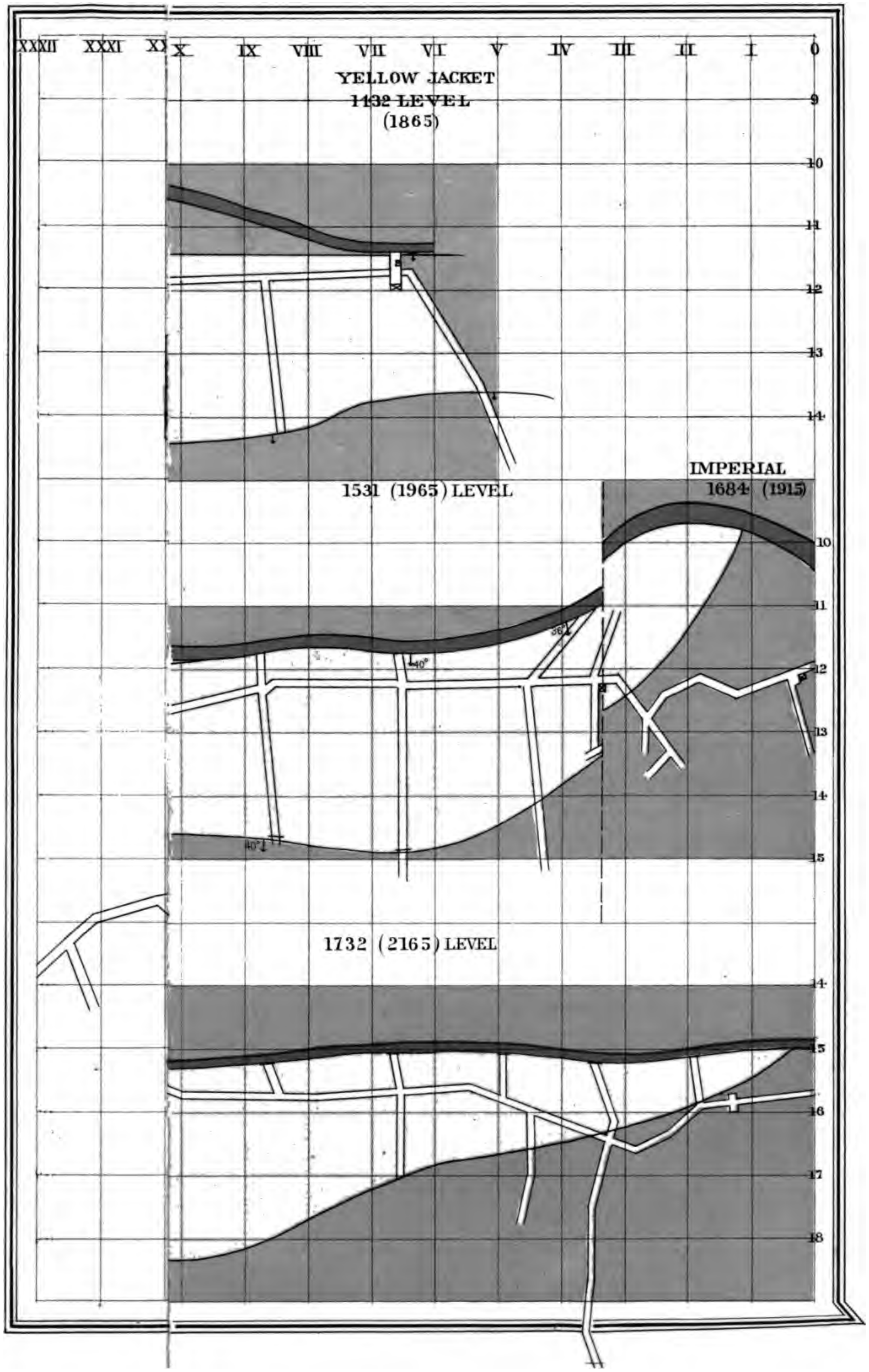
It seems probable that the mineral waters penetrated layer after layer of the propylite through cracks opened at right angles to its surfaces. Similar consequences are common in limestone and sandstone, where ore will leave a parting between two strata, penetrate to a neighboring seam by way of a cleavage plane, and establish itself there in new ground. Precisely that action seems to have taken place on the Comstock, and when small seams are followed for long distances, as in the Ophir, Mexican, Union, and Sierra Nevada ground, there seems to be just this shifting from one side of a stratum to another.

In the old stopes of the Chollar-Potosi, within 300 or 400 feet of the surface, there were two or three places where the quartz followed on its strike was found to abut square against a flat clay-covered surface of the propylite. When followed out these surfaces were cut off by another at a somewhat acute angle, and conforming to the strike of the lode. It seems difficult to devise any other explanation for this situation than that the ore-bearing waters penetrated a cleavage plane and removed the propylite on each side of it, acting on the adjoining surfaces until both were replaced for a considerable distance and thickness by quartz.

Such action as this explains the cone-shape of such stopes as are found in the Consolidated Virginia, and when these sharp angles are found at the junction of quartz and propylite this explanation is a probable one. Where ore is stoped out from the centre of a much larger mass of barren quartz, it often, or usually, consists of an infinite number of small very rich seams distributed in a net-work through the quartz. Separation of the two is impossible, and if it were not for this fact it is not improbable that all the ore in the lode might prove to have a tolerably uniform tenure. The existing difference in grade would in that case depend upon the amount of barren quartz which has served as a dilutent.

Though these suggestions are probable, they are only hints of what may be proved in future, and the sections contained in this memoir have accordingly been constructed in a manner that does not pretend to solve such questions. It is almost impossible to give ideal lines without constructing crescentic shapes, and such outlines are certain to be untrue. In the upper portion of the lode the fractures through the hanging wall appear to have formed in some cases grand sweeps with more regularity than any ore bodies in the lower levels exhibit. There the crescents may have been allowable, but in the true lode formation, below the 1000 foot level, they would be misleading.

Plate II.


XXXII
XXXI
XX
X
IX
VIII
VII
VI
V
IV
III
II
I
0
YELLOW JACKET
1132 LEVEL
(1865)
9
10
11
12
13
14
1531 (1965) LEVEL
IMPERIAL
1684 (1915)
10
11
12
13
14
15
40°
36°
40°
1732 (2165) LEVEL
14
15
16
17
18

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THE MINES.

In the Gold Hill group are comprised the following mines, the list beginning at the southern end of the group: Caledonia, Overman, Segregated Belcher, Belcher, Crown Point, Kentuck, Yellow Jacket, Confidence, Challenge Consolidated.

While exploration has been active over the whole of this area, the works in its southern part have not developed the positive characteristics of the lode, nothing but barren ground being encountered at the depths which were under examination. The Caledonia is worked through a new shaft situated a third of a mile east of the old one, and a fifth of a mile south of it. The new location is 607 feet, and the old one is 497 feet below the datum point designated as "Point A" in King's report, this datum point being not far from 6400 feet above the sea level. A depth of 1655 feet had been reached in 1877 without attaining the black dyke or otherwise developing the character of the west country rock. On the 1255 foot level a drift has been run almost due northward to connect with the Overman, and near the boundary line of the two properties an east cross-cut has explored the adjoining territory for a distance of 900 feet. On the 1455 and 1655 levels the ground has been opened by northeast drifts which in October, 1877, had advanced 500 or 600 feet. All of this ground was found to be porphyrite, presenting such uniformity in appearance as to offer little basis for distinguishing successive depositions. There are few differences in color and texture, the former being mostly light gray and green; but dark colors, dark gray to nearly black, and dark green somewhat similar to the fragments in the Justice breccia, are also found. The action of the water is indicated by a large number of decomposed seams sometimes quite massive, and this decomposition of the prophyrite and introduction of quartz and clay seams was supposed to indicate the position of the lode. It was readily followed from level to level.

The Overman is also working from a new shaft, the third in its history, the last move having carried the works nearly a third of a mile east of their former position. The new shaft is 662 feet below Point A, and had been carried down vertically in 1877 to a depth of 1400 feet. On the 700, 900, and 1100 levels crosscuts were pushed westward toward the west country. The ground contained light colored porphyrite with some alternations of dark gray layers, some well defined decomposed seams and some quartz seams, one of which was followed on the 900 foot level for a considerable distance, about in the direction N. 25 W. In the northern portion of the ground this seems to have a due north course. The new works are so far east that the black dyke had not been reached in the shaft at the 1600 level. The workings were therefore entirely in the east country, and though true "ledge porphyry," containing quartz seams, has been found and followed for some hundreds of feet in depth, the discoveries made are too indefinite to be instructive. On the 1200 level the drift has a very singular shape, returning upon itself so as to form a ∩, the apex of which lies about 300 feet west of the shaft. This drift was the usual main north and south drift opened on each level on the mine, and its remarkable shape was the result of following a clay and quartz seam which turned on itself, forming the ∩. This singular sinus is much more strongly marked than the one exhibited in Savage ground, as shown in Fig. 3 taken from Mr. King's work. That is undoubtedly the misshapen remains of an old trough distorted by side pressure, and there is no reason for denying a similar origin to this horseshoe bend on the Overman.

The Segregated Belcher, Belcher, Crown Point, Kentuck, Yellow Jacket, and Imperial consolidated mines, lie northward of the Overman, occurring in the order given, and covering about 4400 feet of ground. Here the examination proved to be more successful than anywhere else in the mines, and the maps exhibit a minute and continuous plotting of the several quartz bodies which occupy this important portion of the lode. It has supplied vast quantities of ore throughout the history of the Comstock, though not continuously, and its structure exhibits a regularity and simplicity which give it especial advantages as the exemplar of the whole lode. These mines will therefore be considered collectively, though they are not opened in one, but probably in three great quartz bodies. The Segregated Belcher is worked by the Belcher company, and will be treated as the southern portion of their mine. Similarly the Kentuck, containing not quite 100 feet of ground, is worked by the Crown Point, and will be considered with that mine.

It is unnecessary to give a minute account of the levels in each of the mines. They are all opened on the same plan, and though the works in successive mines are not invariably connected, we may describe them in general as consisting of a continuous north and south drift, reaching from one end of the group to the other, with numerous cross-cuts run to the eastward to distances varying from 200 to 600 feet. The ground which was under examination was all below the bottom of the vertical shafts, and opened in depth by an incline sunk with or nearly with the lode by each company. The following schedule exhibits the levels established in each mine, and it shows that the ground has been opened almost continuously at points in the 14th, 15th, 16th, 17th, 18th, 19th, 20th, and 23d hundred-foot distances below Point A. Any continuous level takes different names in the various mines according to the level of its shaft below the datum point. Where the drifts are not on the same actual level, they are connected by short inclines or by winzes when the discrepancy is too great to be overcome in that way.

SCHEDULE OF LEVELS EXAMINED IN GOLD HILL MINES.

Name of Mine.	Level of shaft below Point A													
	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.	feet.
Belcher	414	844	1000	1100	1200	1300	......	1500	1600	......	......	1900	......
Depth of level below Point A	......	(1258)	(1414)	(1514)	(1614)	(1714)	......	(1914)	(2014)	......	......	(2314)	......
Crown Point	469	900	1000	1100	1195	1292	1400	1500	1600	1700	......	......	2000
Depth of level below Point A	......	(1369)	(1469)	(1569)	(1664)	(1761)	(1869)	(1969)	(2069)	(2169)	......	......	(2469)
Yellow Jacket	433	......	......	1119	1229	1330	1432	1531	......	1732	......	1934	......
Depth of level below Point A	......	......	......	(1552)	(1662)	(1763)	(1865)	(1967)	......	(2165)	......	(2367)	......
Imperial Consolidated	231	......	......	......	1450	......	1589	1684	1849	......	2001	(2135)	......
Depth of level below Point A	......	......	......	......	(1681)	......	(1820)	(1915)	(2080)	......	(2232)	(2366)	......

This noble series of openings, made in the most thorough manner through the system of lode rocks, offers extraordinary opportunities to the investigator. Stray clay and quartz stringers have not been followed, or when followed, this labor has been only accessory to the great task of systematically cross-cutting the ground at frequent intervals, in search of the great ore masses which distinguish the Comstock. The facts collected mostly carry unusual weight with them, for they are very rarely indeed based upon single observations, but have been confirmed by repeated discoveries on levels above or below, and in neighboring mines. They show in a convincing manner the regularity of the structure. Its elements are three-fold: the black dyke, the quartz bodies, and the porphyrite.

The Black Dyke is proved to be absolutely continuous. It is developed in every level of the Belcher from the 1000 to the 1900, and at two points, that is to say, in the old south shaft and in the new air shaft, 350 feet north. The

Crown Point incline crosses it, and it is also shown there in every level below the 1100. In the Yellow Jacket the main north and south drift is run parallel with and a little east of the dyke; but west cross-cuts have been opened to it so frequently that its exact position is better ascertained here than in most portions of the lode. In the Imperial it is exposed in cross-cuts on almost every level. Its character as a continuous eruptive dyke is therefore established through the whole of this section. It is uniformly taken to be the western limit of ore-bearing ground, and this lesson has been so well taught by experience that below the first thousand feet of depth no cross-cuts have been made through it, except from shafts lying in the foot wall. The character of the ground west of it was ascertained only in these main cross-cuts run from shafts that lie in the west country, and it was always porphyrite.

In the part of the lode under consideration the dyke lies in two long and not very bold curves, the convex sides of which are toward the east, and separated by a narrow trough.

The most prominent feature of the dyke here is the broad convexity in Crown Point and Belcher ground, in which the rise from the bottom of the trough to the crest of the fold is about 250 feet, in a distance of 800 feet. At the southern end of this bold sweep the dyke appears to bend strongly to the west, but the cross-cuts south of the Belcher South Shaft are neither frequent enough nor long enough to fix its true position. The Crown Point shaft is sunk just in the northern of the two troughs which bound this fold; and north of that point, in Yellow Jacket ground, the dyke turns eastward again and forms a new fold, somewhat less prominent than its southern neighbor.

Quartz has formed on both these folds. In the Crown Point and Belcher the ore was mostly confined to the northern slope of the fold in these mines. What the position of the Jacket ore was cannot now be made out. The position of its barren quartz is plainly given in the maps.

In its turn the Jacket fold in the dyke terminates in a trough which presents new and strong peculiarities. This northern concavity is narrow, abrupt, and proportionally deep, and the dyke after crossing it breaks up into two members one of which seems to pursue its regular way northward, while the other turns to the east at an angle of nearly 40 degrees. The quartz seems to follow the eastern dyke, since the Bullion drift which forms the northern continuation of the Imperial 1684 lies no less than 400 feet east of the Jacket drift, which forms its southern prolongation. The fact of the separation of the dyke into two branches is clearly shown in the Imperial, especially on the 2001 drift. There the main east cross-cut passes through about 50 feet of main dyke, then through 250 feet of porphyrite, after which there is 30 feet of branch dyke. The south drift from the incline runs through the main dyke for 300 feet to the point where the branching takes place. The branch, or rather a dyke vein carrying ore, which faces it on the east, has been followed by a drift which joins the main east cross-cut near the intersection of the two dykes. The branching is also clearly shown on other levels of the mine.

The Quartz Bodies. Two immense bodies of quartz lie stretched along the great curves of the dyke in the region of this group, and a third, much less important, is opposite the branch. For the most part they are not solid masses of quartz, but a mixture of silica, clay, and porphyrite. Even where the ore is most abundant, the quartz is not pure. Comstock ore is called quartz in the vernacular of the miners, but it is usually a mixture of quartz and porphyry; and the fact is all the more important because the barren bodies appear to be more nearly pure silica than the ore quartz. The former is dense, firm silica, and, by the singular perversion of terms that is so often found in empirical language, it bears the name among the miners, of *bastard* quartz. They give the name bastard to true quartz, and the name quartz to a mixture of silica and clay or porphyrite, because their term "quartz" signifies that rock which either does or is likely to carry ore, and true, firm, solid quartz does not enjoy that distinction so often as the mixture.

In this book an equally forced application of terms is necessarily made. The word QUARTZ is applied first, to all *ore*, of whatever composition; second, to quartz as known to the mineralogist; and third, to any mixture of quartz and clay or porphyrite, which contains 50 per cent. or more of visible silica. Below that percentage the mixture is here called "ledge porphyrite." The term porphyrite is used to distinguish that rock when removed from the decomposing influences of vein waters. In some cases it contains thin, hard quartz seams; but they have been introduced without effecting any alteration of the surrounding rock, unless to a very limited extent.

I. From the south the first of the quartz bodies is that which enveloped the famous Crown Point and Belcher bonanza. It has a length of 1400 feet, and it is not impossible that some of the quartz seams in the northern Overman might be proved to be connected with it, adding several hundred feet to the above estimate. Its shape is well displayed on the 1500 foot level of the Belcher and Crown Point. (Plate II.) At the Belcher South Shaft its thickness on this level is about 50 feet, while 400 feet further north it expands to three times that thickness, or 150 feet. As an undivided quartz body it continues 450 feet south of the Belcher shaft, tapering to a point. But in the Crown Point ground there are two parallel thin bodies of quartz lying just outside the first described quartz, but belonging to the same mass and connected with it on the 1400 level. We must look upon this formation as a quartz body which retains its integrity with remarkable persistence for 900 feet in length; but in the 500 feet which constitute its northern termination splits into three branches by the preservation within its mass of long, thin leaves of ledge porphyrite. These three branches are completely united on levels above this, but the thickness of the quartz is at the same time reduced. Considering these three parallel strips together, we have a quartz body which, beginning in a thin seam south of the Belcher South Shaft extends northward with a very regular and gradual taper for 700 feet to a thickness of 150 feet and continues in a slightly increased thickness for 500 feet further, when it rapidly thins out to a wedge lying in a thick mass of ledge porphyrite highly altered. Its shape is therefore well defined as that of a lens. In the vertical direction this lenticular shape is also preserved, so far as the lower terminations of the quartz are concerned, the upper terminations not being visible now. The splits which have produced three ledges of quartz in the northern portion of the mass, are also maintained for long distances, and these ledges are shown to run into the main body to the north and also on the upper levels, so that these outer ledges are joined to the main mass on two of their edges.

II. North of the Crown Point and Belcher lies the Yellow Jacket body, one of the most massive accumulations of quartz in the whole Comstock lode. It reaches the surface at the Old Jacket shaft, and extends with well preserved dimensions to the 1732 level, and below that point there are thin quartz seams reaching to the 2200 level, which are its feeble prolongations. It has a total length of about 1300 feet, and a thickness that surpasses 300 feet on several levels. In the upper portion it contained the large quantities of ore that made the name of Yellow Jacket so famous; but this gave out at the 1028 level, and has not since reappeared, the disappearance of ore being coincident with the sudden and marked flattening of the dip already spoken of.

Near the surface this quartz body was reinforced on the west, as Mr. King's maps show, by a parallel mass of quartz having a west dip, and forming the famous "West vein" of the Gold Hill mines. It gave out suddenly by abutting on a flat portion of the foot wall. The lower or "East vein" lay at a greater depth for the larger portion of its length, and is the mass which the Jacket has explored at all levels below the 400. It is even more strikingly lenticular in shape than the great sheet in the Belcher and Crown Point. It begins apparently with a thin seam, its southern end being shown in the Crown Point 1100 level, where it overlaps the quartz body of that mine by 200 or 300 feet, the two quartz masses lying *en echelon*. Its thickness increases much more rapidly than its southern neighbor, for in the first east cross-cut, south drift, of the Jacket 1531 level, where the quartz has been cut entirely through only 50 feet or so from the Kentuck line, it is found to be 250 feet thick, having increased from a mere wedge to this dimension in 400 or 500 feet of northing. This rapid thickening is obtained by the strong western direction of the western edge of the quartz, which continues until it runs against the dyke 700 or 800 feet from its beginning, and just north of the Jacket shaft. At this point its thickness is 300 feet. The quartz apparently hugs the black dyke for 700 feet, following the undulating line of the dyke which has been described as lying north of the great Crown Point and Belcher bend. Just at the Imperial line where the dyke begins its sharp western turn in that ground, occurs the northern point of the lens, and this is quite obtuse, as that in the Crown Point bonanza also is. The eastern side of this Jacket quartz is not parallel to the line of the dyke, but has some strong sinuosities, one of which produces the greatest thickness of quartz observed on the Comstock, 350 feet. At this point it has been cut through by the Jacket second east cross-cut, north drift. From that point the east boundary of the quartz sweeps strongly to the west and joins the west boundary in the strong concavity formed by the dyke between the Gold Hill and Virginia groups of mines.

The shape of this magnificent quartz body is determined from observations made in the Jacket 1531 main drift, which is open for about 900 feet in length; from the position of the east clay marked in four out of the five east cross-cuts, which entirely intersect it in a length of 1000 feet; and in six west cross-cuts which define its western boundary. The long east cross-cuts, most of them 300 feet long, are not open except on the 1119 level, and the constitution of the mass has been ascertained on the 1531 level by inspecting the long main drift and west cross-cuts. The exact position of the termini of the lens is doubtful, though inferable with considerable certainty from the direction of the boundary lines. In spite of these minor deficiencies the tremendous mass is exhibited by the well planned works through 1000 of its 1600 feet of length, and over three-quarters of the 360,000 square feet which its plan on the 1531 level covers. Its vast dimensions are nearly maintained on other levels, as on the 1119, the 1330, and the 1432. The dimensions already given for the 1531 level would almost apply to the three others, and also to the 1732, though there are changes of form, and the thickness is somewhat diminished. This diminution appears to be more marked below than above the 1531 level. From the 1119 there is a gradual increase of thickness down to the 1531 where the culmination is reached, and then a more rapid thinning takes place, until on the 1932 the plan does not cover half the area it has on the most extensive level. This diminution is the result of thinning of the mass, its length appearing to be somewhat permanent.

The changes in shape are, however, less prominent than those in its constitution. On the 1119 level, which for a wonder still remains open through all its cross-cuts, in spite of the risks it suffered in the great fire which raged here in 1873, is one huge mass of quartz, most impressive in its vastness and homogeneity. Even on the Comstock, where quartz deposits of extraordinary dimensions are the rule, it is not often that this mineral is found in such quantities, and so little mixed with porphyrite or clay. But this condition of things is altered on the 1531 level, the two intermediate levels being closed. In the main drift of the 1531, which is open for more than nine hundred feet, we obtain a clear and most instructive picture of the interior constitution of the mass.

Here it is no longer a homogeneous deposit, but is made up of successive streaks of quartz and ledge porphyrite, crossing the drift at various angles, but exhibiting a general parallelism. These streaks, as shown in their oblique section, are from 35 to 90 feet thick, and the ledge porphyrite often, but not always, contains so much quartz as to make its proper designation a matter of doubt. These alternations continue until the Imperial line is passed, the connection between the two mines being effected by means of a winze about 50 feet high. They are succeeded by about 400 feet of ledge porphyrite, containing some quartz, but very much less than the rock which has been given this name in the Jacket. This mixed composition is also characteristic of the quartz in all levels below the 1531.

On the lower levels the quartz of this great body is found to occupy a position of continually decreasing importance while the included propylite widens and thickens. Clays mark what may perhaps be considered the extreme limits of the great mass; but its composition is now predominantly porphyrite, and the quartz is mostly confined to the neighborhood of the black dyke. Throughout the mines, the dyke is seen to be accompanied almost constantly, though not invariably, by a thin seam of ore-bearing quartz, always too thin to be of importance when not supported by other accumulations in its neighborhood. In the 1934 level of the Jacket the quartz lies near the dyke, some of it in this dyke vein and some in parallel seams east of it. East of them, but still within the recognized limits of "the vein," as this quartz-carrying area is called, is a thick mass of porphyrite much decomposed, but without quartz enough to cast even a doubt upon its true designation as porphyrite.

The great importance of the Yellow Jacket quartz deposit in a theoretical sense has already been pointed out. Taken with the equally significant Justice and Consolidated Virginia-California ore bodies, it supplies incontestable evidence of the mode in which the Comstock lode was formed.

Between the two quartz masses which have been described lies a small deposit of this material which seems to be separated from both by a well marked clay band. If it belongs to either it must be placed with the Crown Point body, but in the maps it is represented as distinct from both. It contains no ore, and as a consequence has not been explored sufficiently to make its true relations evident. It lies between the extremities of its two greater neighbors, flanking the Crown Point quartz with its southern and the Jacket quartz with its northern end. Bodies disposed in this position are not novelties, and this one does not call for further discussion.

III. Following the Jacket quartz on the north, and about 400 feet distant, lies a thin seam which has great interest both from its position and from the fact that it is clearly the beginning of the great Virginia system of ore bodies. Many fanciful divisions of the Comstock have been made, some erring by extreme localization of such phenomena as were observed, and others equally at fault in their attempts to establish wide groups. Most of these efforts to explain the system of the great lode have been based upon the occurrence of *ore*, which was but a second step in vein-making. No one who observes the situation of this third quartz mass can doubt that it really represents the Virginia series of quartz bodies, though its direct connection with those deposits is unfortunately lacking owing to my inability to examine the intervening Bullion mine before the close of the field work.

The branching of the dyke in the Imperial Consolidated has been described already, and the new quartz forms a thin seam lying, like all other quartzes, immediately east of the branch. Like the latter it has a course nearly due north-east for about 600 feet, sweeping then in a gentle curve toward the north, until in 400 feet more it lies north and south, the general direction of all the Comstock deposits. In Imperial ground it is apparently nothing more than a dyke vein, ore-bearing and in fact worked for ore, but too thin to be valuable. When it assumes the north and south direction, other outlying seams of quartz begin to accompany it, and we have the usual alternation of quartz and decomposed porphyrite. Some of these outlying seams have been opened by the Bullion, but none of them have yielded paying ore in this ground. It is near the southern commencement of this third quartz body that the datum line already spoken of has been established.

The Country Rock is the third component of the lode. In Gold Hill this is propylite both east and west of the lode, and this rock reaches from the Caledonia into Bullion ground, passing the point in Imperial Consolidated, where the Virginia quartz masses have their origin. The northern or Virginia group of mines therefore covers a portion of the lode which has exhibited a somewhat noteworthy succession of changes in its country rock. At the surface diorite and metamorphic strata stood on the west for part of the section, and propylite and metamorphic rocks for the remainder. When the first 500 feet of depth was passed, a simpler condition of things was entered upon, and propylite filled the east country through the whole distance, while the west country was made up of diorite from the Utah to the Bullion, where the Gold Hill propylite appeared on both sides the quartz. Still deeper, and at about 1400 and 1500 feet from the surface, a broad ledge of diorite is said to have revealed itself in the central portion of the Virginia group. Standing in the position of propylite, east of the dyke, it was so extensively removed by the substitution of silica for the original rock that in no case has it been found on the east of the quartz, though it is reported to stand as a portion of the horse enclosed in ore in the Consolidated Virginia.

The character of the lode rocks has been so fully considered in the foregoing pages that it is unnecessary to enter upon a new description of them, and only a few subjects will now be touched upon.

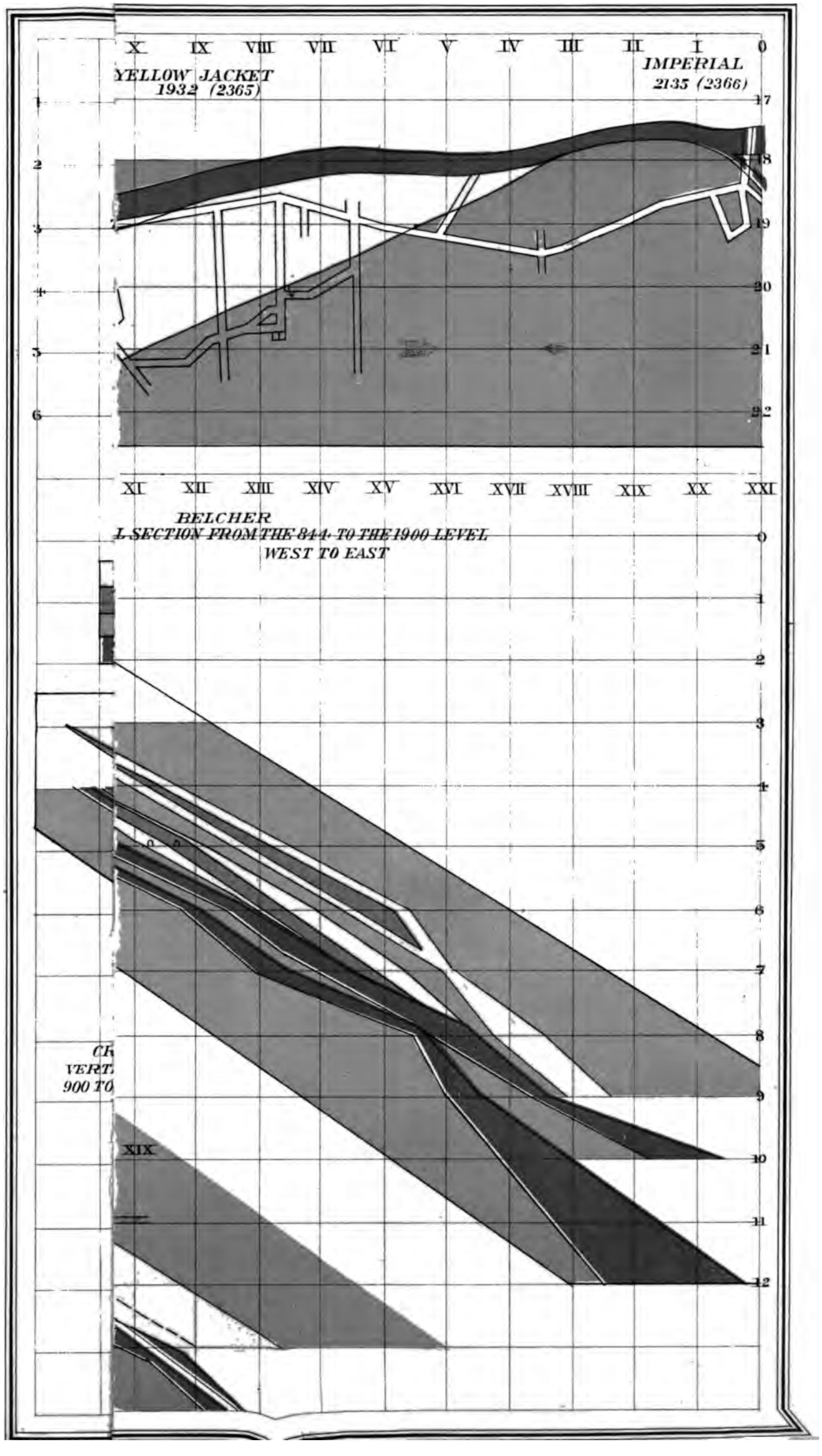
With so few salient points to attract attention it is not surprising that the characters of the propylite are with difficulty traced and localized from level to level. The most successful instance of this is given by the white porphyrite mentioned by King as occurring in the upper levels of the Belcher. This continues, confined to that locality, for thousands of feet in depth.

Another noticeable occurrence is that of the rock which has been called hornblendic porphyrite, and which seems to be a diorite in composition, with the addition of a paste in which the usual crystals are set. This dioritic rock is confined to the southern portion of the region, where the metamorphic strata are most developed. It rises through them in thin leaves as seen in the west cross-cut from the Justice drain drift. In the propylite it forms layers parallel with those of the surrounding rock and reaching to 75 feet in thickness. No surface exposure has been mentioned, and it is most probable that it appeared as single and isolated members of the propylitic flows.

That variety of propylite in which milky-white feldspar crystals are distributed through an amorphous paste is invariably styled " bird's-eye porphyry" by the miners, though the crystals are rarely rounded. This variety is highly esteemed on the Comstock as an indication of the near presence of ore, or at least quartz, and this reputation is maintained in spite of innumerable disappointments. There are of course differences in this " bird's-eye," but even the most significant variety, which any miner will acknowledge to be a happy augury of approaching "developments," has proved a faithless guide in hundreds of cases. Still though this rock is not an infallible test of ore ground, it seems to be in truth a companion to the quartz wherever the latter is found. Whether it is the product of vein waters acting upon the propylite cannot be decided without closer study, but there is some probability that this is the case. Strata of propylite that elsewhere are free from these porphyritic developments will show the crystals on one side lying next the quartz. It is not to be understood, however, that this "bird's-eye porphyry" is an invariable component of the lode, or that being found on one level it will appear on the next level, above or below. It is capricious, and this capriciousness is its only fixed characteristic.

In the Virginia group only two mines have been mapped, the Consolidated Virginia and California, and as neither of these exhibited any thing but ore-bearing ground, the description of them has been placed in the following chapter.

Plate III.



X IX VIII VII VI V IV III II I 0
YELLOW JACKET
1932 (2365)
IMPERIAL
2135 (2366)
1 2 3 4 5 6
17 18 19 20 21 22
XI XII XIII XIV XV XVI XVII XVIII XIX XX XXI
BELCHER
L SECTION FROM THE 844 TO THE 1900 LEVEL
WEST TO EAST
0 1 2 3 4 5 6 7 8 9 10 11 12
CR
VERT
900 TO
XIX

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CHAPTER VII.

THE POSITION OF THE ORE.

In a previous part of this memoir it has been asserted that the ore bodies occupy the steeper parts of the lode, and that ore occurs *nowhere* else; and a portion of the evidence on this subject will now be presented.

The Yellow Jacket, the Consolidated Virginia and California, the Crown Point, and Belcher, and finally the Justice bonanzas, will be appealed to in proof of the fact.

The Yellow Jacket offers the best proof of any mine on the lode, though during the time of the examination, and for several years before, not a pound of ore was discovered in it. Its ground is divided in depth into two great portions, each homogeneous in itself. The upper, or ore-bearing territory, is well exhibited in Mr. King's maps, and the lower barren section was open to careful examination during my own field work, and is exhibited in plans of each level on plates I. and II. Plate III. contains a vertical section taken through the shaft, the upper part down to the 1028 level being copied from Mr. King's work, and the lower part with the exception of that one level being plotted from my survey.

Plate III. shows the relative positions of these two portions. From the surface to the 1028 level ore was found almost continuously, though it was separated into a west and an east ledge. A glance at the map will show that the whole of this upper portion has a very steep dip, the west ledge having a west dip of 30 degrees, and the east ledge standing within 10 degrees of the vertical. Below the 1028 level the dip of the quartz changes suddenly to about 35 degrees from the horizontal. The two parts of the lode therefore differ by 45 degrees in dip.

Precisely at the point where this change takes place the ore fails, and the situation is so plainly shown by the section that description is unnecessary.

By the common usage of the district the quartz below the 1028 level is known as the " Jacket barren body," and the impression is general that it is a separate mass from the ore quartz above; but this section shows them to be entirely continuous. The quartz is continuous, but the ore is confined to the vertical portion, though the lower part carries very much the larger mass of quartz.

Reference to Plates I. and II. will show that when examined on the strike this vast deposit of quartz is found to sustain the relations which it has been asserted all these bodies have to the black dyke. It occupies a position opposite a great curve or boss of the west wall. This projection is included between two troughs, one in Imperial ground and one in the southern part of the Jacket. It is less strongly marked than some others on the lode; but the 1119 and 1531 levels, which were in the best condition for exploration, show its curvature very plainly. The northern end of the great quartz body, for 600 or 700 feet of its length, is applied quite closely to the dyke, but its southern end is projected toward the east so as to leave a thick mass of propylite between the quartz and dyke, and finally overlaps the Crown Point ore body. It has been cut in east cross-cuts of the latter mine.

In regard to the sections, it should be mentioned that the exact dimensions of the quartz are given on the authority of the mine maps with exception of the 1119 and 1531 levels. In the others the cross-cuts had been filled with waste rock to avoid the expense of hoisting, and exploration of them was impossible. It is probable that the dimensions given to the 1732 and levels below it are excessive. The east line of the quartz is fixed by the position of a clay which is picked out from a number of similar and parallel clays as being the "east clay," but the mass enclosed between it and the west boundary, though always colored as quartz on the maps, varies decidedly in composition. On the 1119 level it is a vast deposit of almost solid silica, on the 1531 it contains so much ledge porphyrite that probably not more than two-thirds of its quantity is silica. Below that point the proportion of propylite included in the so-called "quartz" increases with each level until on the 1900 it is probable that silica does not fill one-fifth of the section, and what is found is chiefly massed near the black dyke.

This mine is extremely valuable to the student because it is the only one on the main lode in which the successive surveys complete each other. For this reason it offers a view of the whole lode from the surface downward. It is not, however, otherwise the most striking. The four mines which are represented in section exhibit different characteristics as follows:

1. The Yellow Jacket shows very clearly the relations of the rich to the barren quartz.

2. The Consolidated Virginia and California ore bodies show how an eastward-dipping lode can contain portions which are not only vertical, but are thrown into a reverse dip. They also illustrate the formation of ore on the lower side of a dome, and the wonderful results that can be produced from the pressing apart and crushing of strata in such a situation by the effect of an overpowering weight.

3. The Crown Point and Belcher body on the contrary shows that steep dip is not necessary to the formation of ore; but that it has been deposited in portions of the lode which had but a moderate slope, when these parts were more inclined than those above and below them.

4. The Justice is an example of extreme irregularity, of an ore body that partly lies at right angles to the west wall instead of parallel to it, and of violent changes in strike.

The only ore bodies open to view in the Virginia mines during the time of this examination were those which have been sufficiently famous to become known as "the great bonanzas." This term has been applied to only two of the mines, but the three bodies included in them form a part of a composite mass, lying in Consolidated Virginia, California, and Ophir ground, and containing four distinct ore bodies. These vary in almost every respect, size, shape, dip, and strike, but they appear to have yielded ore of tolerably uniform high grade, the average yield in the mill having for years been about $108. To this should be added the losses in treatment, and also the value of the battery slimes, which by the western system of milling are not included in the returns. Probably the total assay value of the ore up to 1879 was between $130 and $150 per ton of 2000 pounds.

Three of the ore bodies are disposed in a general north and south direction, but the other, which is in Ophir ground, and therefore north of the others, has a strike which is about N. 65 E., and accordingly lies almost at right angles to the general line of the series.

The quartz bodies in which these rich ores are contained appear to be fewer in number. So far as made out they consist of three, one containing the large Consolidated Virginia ore stopes, another north of this, and carrying the small Consolidated Virginia ore body, and a third which encloses the California ore and the stopes of the Ophir.

The relations of these separate depositions of ore are so intricate that they cannot be understood without close attention to the maps. Plates XII. to XIX. exhibit the levels, giving six horizontal and the same number of vertical sections. Others showing longitudinal and cross sections will be referred to in the progress of the description.

The principal of these deposits is the southernmost, lying mainly in Consolidated Virginia ground, but pitching northward into the California claim. Ore was first struck on the 1200 level, 1360 feet below "Point A," and 6100 feet north of that datum line in Imperial ground which has been assumed to mark the separation of the Gold Hill and Virginia groups of quartz masses. It extends over 800 feet on the lode, has a maximum vertical height of probably 500 feet, and a maximum thickness, at right angles to the side boundaries, of somewhat more than 200 feet.

Lying north of this magnificent deposit, and directly in its strike, but separated by a horse 30 to 50 feet thick and said to have been composed of diorite, was the second of the ore bodies. Very much smaller than either of its neighbors, it extended from above the 1300 to below the 1500 level, or approximately 275 feet. Its greatest length appears to have been 90, and its greatest thickness 50 feet. This mass was entirely closed to observation by the caving of the ground, but its position is accurately marked by the stopes. The interesting occurrence of diorite in the intervening horse could not, however, be examined, and it is mentioned here on the authority of a paper on this subject, presented by Mr. Mellville Attwood, of San Francisco, to the California Academy of Science. On the maps it is colored as propylite, as nothing is known of its dimensions.

Next on the north is the California bonanza, third in order, but second in importance. This covers about 300 feet in strike, 200 in vertical depth, and probably 120 feet in maximum thickness. Its shape is unusual. Making its first appearance above the 1500 level, it thickened with extraordinary rapidity, attaining a section of 110 or 115 feet on that level. These dimensions were pre-

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served on the 1550, but sank to about 60 feet on the 1600. All of these dimensions refer to levels above the 1600, which was the lowest point sufficiently explored for mapping at the close of 1877. Ore has been found on lower levels, but somewhat distributed in "bunches."

From the quantities given it will be seen that the size of these bonanzas was by no means extraordinary for the Comstock except in one direction. All three were extremely thick for their length, but in one respect they lost ground as compared with rivals of much less fame and merit. They stood nearly vertical, so that the depths of the levels represent nearly the true height of the mass, while in ore bodies that are much inclined, the true length may be nearly one-half greater than the vertical height. But this small disadvantage was so richly compensated by the vast thickness of all the masses that more than 1,000,000 tons of rich ore, yielding somewhat above $107,000,000 had been extracted from them up to the close of 1877. To this was added in 1878 about 258,000 tons of a poorer ore, which yielded $18,955,832, or very nearly $73.50 per ton.

This system of ore deposits is completed by one in the Ophir mine. This extends from above the 1600 level of the California (Ophir 1465) down to a point probably 150 feet lower. It forks at the 1465 level, where the two prongs have a joint length of about 140 feet, and a thickness of less than 60 feet. The yield of the Ophir for the years from 1874 to 1877 inclusive, was $2,251,455 in gold, and $2,602,123 in silver, total $4,853,578. This was probably drawn entirely from these stopes and from bunches of ore near them, and swell the total product of the whole system of ore bodies in this group to more than $130,000,000.

Taking these five deposits together, with their intervening country rock, they cover a length of about 1400 feet on the strike of the lode, and a vertical height of 500 or 600 feet.

The size of the barren quartz masses which enclose the ore stopes is only roughly known. The southern termination is given with approximate correctness on the 1300 and 1550 levels; but elsewhere it is mostly conjectural, the few points which are known being marked by uncolored drifts.

The southern termination of the ore is formed by a thin seam lying in a thicker mass of quartz and propylite. Its vertical extent was not observed, but it appeared to run only a short distance above the 1200 level. The first section on the map is taken about 100 feet north of this point, and even here the ore does not rise high enough to reach a new level above, nor sink low enough to intersect the 1300 level. A further distance of 100 feet northward brings us to a point which extends through a vertical height of more than 138 feet, and also shows ore on the 1550 level. From that point the apex line falls 400 feet in a distance of 500 feet, or at an angle of about 35°. Then a long tongue runs out to the north, with but a slight pitch ; but its vertical height was not ascertained at the time this examination closed.

The northern edge of the rich ore combines with its upper line to form a slope, bounding the ore body on the north and west. For the upper 200 feet the same state of things is found on the southern and eastern sides. They are combined in one line, sloping to the north, and nearly parallel to the upper line. But below the 1400 level a different state of things exists. The southern line is vertical, with a bulge to the south at the 1500 level, and the lower line is almost perfectly horizontal, being as constant in its level, for a distance of 400 feet, as the upper line is persistent in its pitch.

Laying these lines out on the scale of 200 feet to one inch, we obtain the Fig. 5, p. 113, which, however, is given as a graphic summary of the information obtained, but not as a final determination of all the facts. Exact conclusions concerning the shape of this singular mass cannot be formed without a more thorough knowledge of the true position of boundary lines than could be obtained in a fortnight's inspection of mines whose vast excavations in treacherous ground required the permanent closing up of the openings as fast as they were exhausted. On this account the position of the several floors lying between the 100-foot levels could not be obtained, and the outline is therefore drawn through points most of which are separated by 100-feet vertical distances. On the 1500 level the southern terminus of the quartz could not be reached, and in the map the known points at this spot are connected by the shortest possible lines, giving the level its minimum extent. But whatever doubt exists in the outline given applies only to details, the position of the stopes being accurately known from the current mine surveys. Accordingly the sketch shown in Fig. 5 is given as an outline of the rich ore bodies included in the quartz, and not of the quartz as a whole. No. 1 is the larger, and No. 2

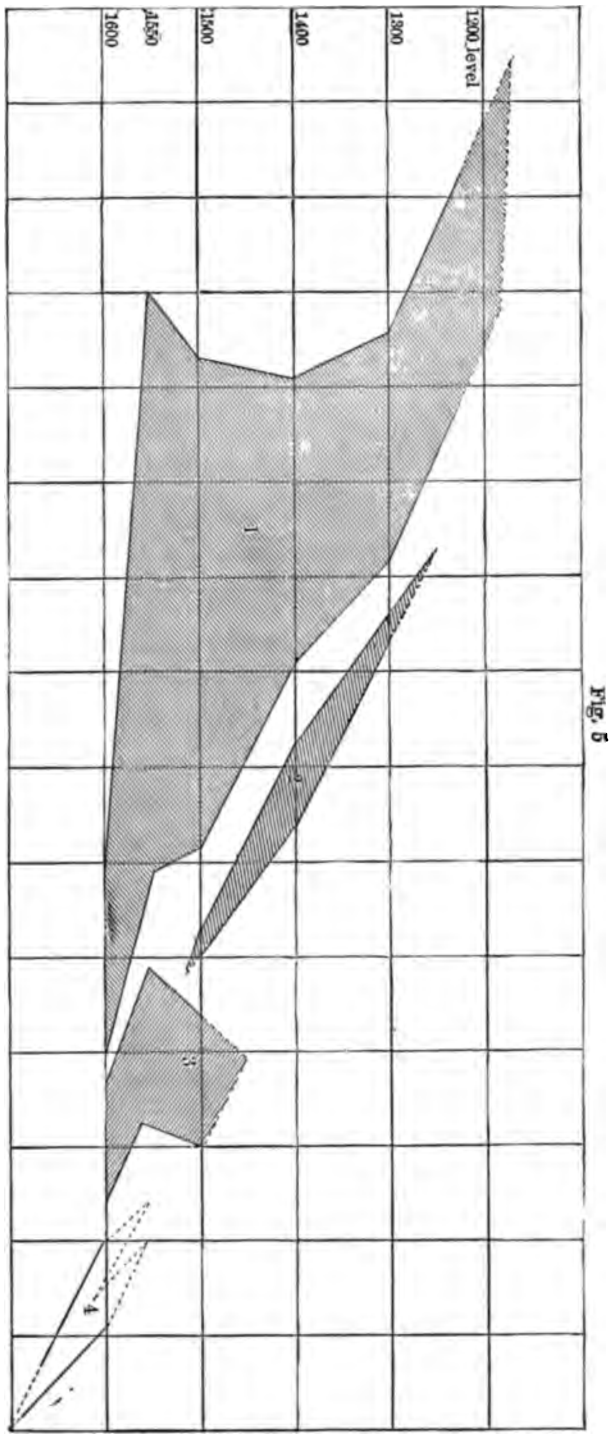


Fig. 5

the smaller Consolidated Virginia ore body, No. 2 the California, No. 4 the Ophir stopes.

A peculiarity of this body is that the thickness of the mass at any point has a certain proportion to its length there. The thickest portions coincide with the longest portions; and it is to this fact that the vast production from ground comparatively moderate in extent has been due. But a true conception of the conditions exhibited can be obtained only by considering all four of the ore bodies together.

An examination of the sketch will show that they occupy two lines approximately parallel. The southernmost is filled by the great Consolidated Virginia main ore body, and north of this lies a group composed of the smaller ore body of the same mine, the California and the Ophir ore bodies. It is common to find a great quartz mass broken up in this way; but the interleaved layers of propylite have hitherto lain parallel to the general strike of the lode, while in this case they cross it.

The longitudinal dimensions of these bodies, as measured on the maps, are as follows, taking the great Consolidated Virginia bonanza first:

Beginning with a thickness of about 30 feet on the 1200 level, the stopes descend to the 1300 level with a northward pitch, and a general length of a little more than 100 feet when measured at right angles to their pitch. On the 1300 their southern boundary loses its pitch toward the north, and begins to descend almost vertically, the northern line continuing as before. In consequence, the stopes gain steadily in length until on the 1500 level they measure 500 feet from south to north, following the curved line of the ore. In thickness they vary from 40 to 185 feet.

Opposite this mass, and separated by diorite and propylite, about 40 feet thick, lies the smaller Consolidated Virginia body, which increases the total length of the 1300 level to about 270 feet of quartz, and 55 feet of country rock. On the 1400 there is 400 feet of quartz, and 80 feet of horse, and on the 1500 there is 560 feet of quartz and 70 feet of horse. There the outside body ends, and the California bonanza enters the field. All three are shown on the 1500 level, which accordingly has a total length of 700 feet in stopes, and about 130 feet in country rock disposed in two horses. The California bonanza is here about 140 feet long, and has 60 feet of propylite separating it from the intermediate small ore body.

Below, on the 1550 level, the lengths are as follows : Consolidated Virginia ore, 500 feet ; propylite horse, 100 feet ; California ore body, 165 feet. Of the latter about 50 feet lie in a tongue which runs southward from the main mass of the stopes, the latter being somewhat more than 100 feet long.

These vast dimensions of the rich ore are suddenly curtailed on the next level which is only 50 feet lower down. Instead of 500 feet in the Consolidated Virginia ore body, there are only 200. The great mass, which has extended in dimensions constantly increasing in every direction from the 1300 level, here finds a floor that cuts it squarely off over a considerable area. The northern line of the ore increases its already strong pitch ; and though ore has been found on lower levels it must be in much decreased quantity. At the same time the northern line of detached bonanzas diminish in length, though the appearance of the Ophir ore on this level replaces a small portion of the loss. The quantities on the 1600 level are: Consolidated Virginia ore, 200 feet in length ; propylite horse, 50 feet ; California ore, 165 feet ; poor or low grade quartz, 100 feet ; Ophir stopes, 50 feet.

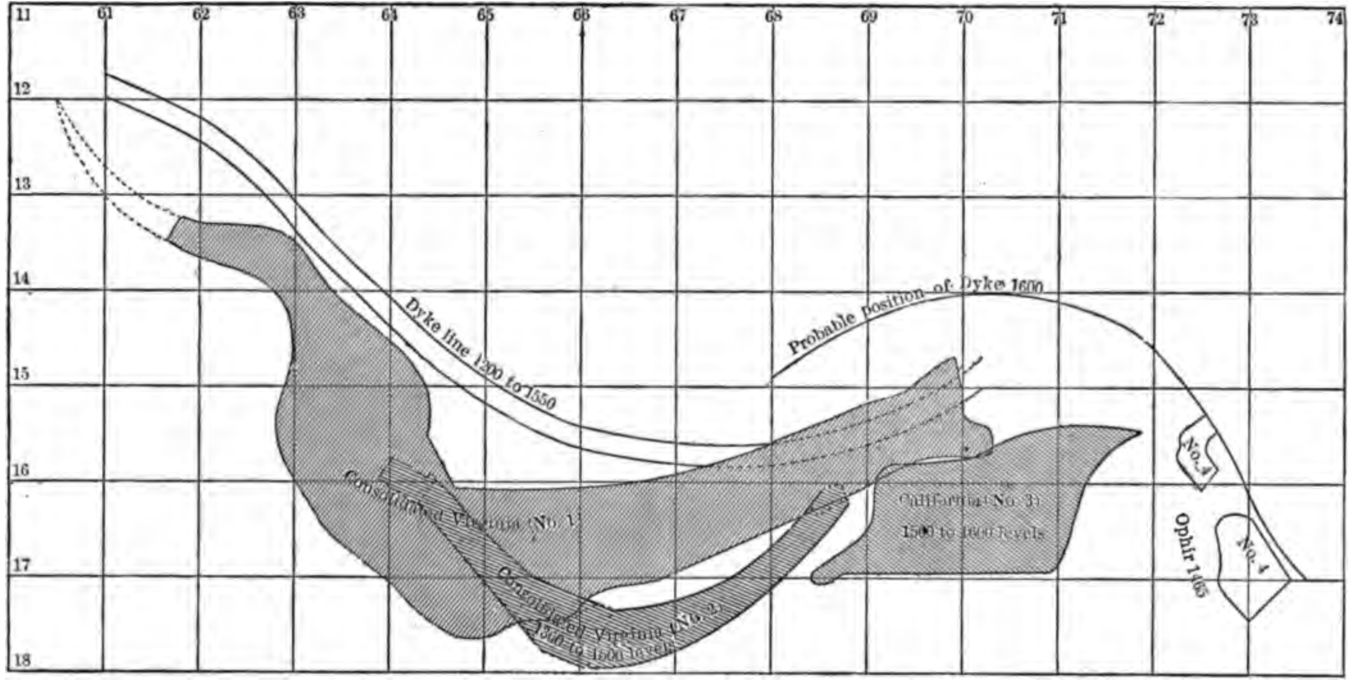
Though the 1650 level had been opened and had furnished ore when my examination was made, its development was not sufficient to show its probable extent ; and the only lines that can be continued down are those of the Ophir ore, which are extended 135 feet further. They pitch so steeply to the north as to carry down with entire accuracy the sloping northern line of the other bonanzas.

Taking up next the horizontal contour of the ore bodies as exhibited when projected on one level, we find that they and the dyke which accompanies them are bent as in the following diagram. The sketch, Fig. 6, also shows how the ore on some levels overlies the dyke at greater depths ; but all the occurrences of this kind are not indicated.

This shows that the "great bonanzas" rigidly fulfil the unvarying conditions of ore depositions in the lower levels of the Comstock, and are bent upon a strong curve in the black dyke.

It will be noticed that at the northern end where the Ophir ground is situated the west line makes a sudden and strong turn toward the east. The cause

Fig. 6



THE FOUR ORE BODIES OF THE "BONANZA MINES,"

CONSOLIDATED VIRGINIA, CALIFORNIA AND OPHIR.

All levels referred to one plan, showing relative positions of Ore Masses and of the Black Dyke.

Scale 200 feet to 1 inch.

of this brings up the especial peculiarities of all this part of the Comstock, and carries with it important considerations affecting the fortunes of all the mines that are working here.

This eastern turn is caused by a bold jutting of the diorite which advances 500 feet eastward in making a northing of equal amount. The southern side of this projection therefore has an average slope to the strike of about 45°. North of this in the Ophir, Mexican, Union, Sierra Nevada, and Utah mines, the explorations disclose an unbroken continuity of diorite in a position further east than was to be expected from the dip of the west wall on higher levels.

It is probable that we have here a repetition of the strong fold now forming the divide between Virginia and Gold Hill. The two ridges are essentially parallel and of not very unequal height, though that of the divide is the more persistent in vertical extent and apparently broader.

Combined with this cross-fold there appears to be another which follows the strike of the lode. The Consolidated Virginia bonanza terminates by a sudden giving out of its quartz which apparently loses nothing of its massive proportions in anticipation of its termination. There is no thinning out as it approaches its end; but the vast mass is suddenly cut off between the 1550 and 1650 levels, and has only large outlying bunches of ore for its continuation in depth below the latter.

This behavior may be accounted for by supposing that the ore body lies opposite the eastern or under side, and stands upon the western, or upper side of one of those lesser waves which have been spoken of as riding upon the slope of the principal elevation of the Virginia range. In consequence of this fold the contact line of diorite and propylite must be carried considerably to the east of its position opposite the ore ground, and within some distance, not very great, of the 1600 level. Lower down, the line of the lode is probably about the same in the Consolidated Virginia and California as in the Ophir ground, though on that level the west wall of the latter stands far east of the neighboring stopes.

The vertical cross section of this composite mass of ore bodies is not less interesting than its corresponding longitudinal section. Examination of Plate V. will show that the country rock is here folded into a sharply waving outline for a height of about 500 feet, and that the mean of all the undulations is near a vertical line, some of the inclinations being toward the east and others toward the west.

Section No. I. represents the southern end, about 100 feet from its extremity, and also the highest point of the Consolidated Virginia large body. Disclosed on one level only, the lines of the ore are necessarily altogether conjectural. In this section the line of the quartz is represented as broken at the 1500 level. In fact, it may be continuous, though the southern extension of quartz on this level is less than on either of its neighbors. No. 2 shows the outlines 100 feet further north, following on the curve of the ore. In this short distance the development has been so great that we have a height of about 150 feet in the stopes, besides an unknown height above the 1200. At section No 3, 100 feet further on the curve of the ore body, the height has fallen, owing to the pitch of the north line of the ore; but the section shows ore down to the 1550 level and below. At section No. 4 the height of the stopes is about 200 feet; at No. 5 it is about 150 feet; and at No. 6 it is about 25 feet less. The longitudinal section given above shows that all this diminution is produced by the pitch of the northern limit of the ore body.

The thickness of the mass is less constant than its length, or, more properly, it diminishes by a less constant quantity, and exhibits fluctuations. Beginning with a true thickness of about 45 feet on the 1200 level, it increases in section No. 3 to about 70 feet, and again diminishes to about 15 feet, at which thickness it runs out below the 1550 level. At section No. 4 the average thickness is somewhat greater; and here it begins to exhibit a tendency to increase from the 1500 level downwards, and this tendency leads it in 200 feet more to the formation of a mass 185 feet thick, the greatest true section in ore ever known on the lode. By *true section* is here meant one which is taken at right angles to the dip. On the horizontal, as the levels are opened, and in an east and west course, as the cross-cuts are run, the sloping curved mass gives a section which is in places nearly 100 feet greater.

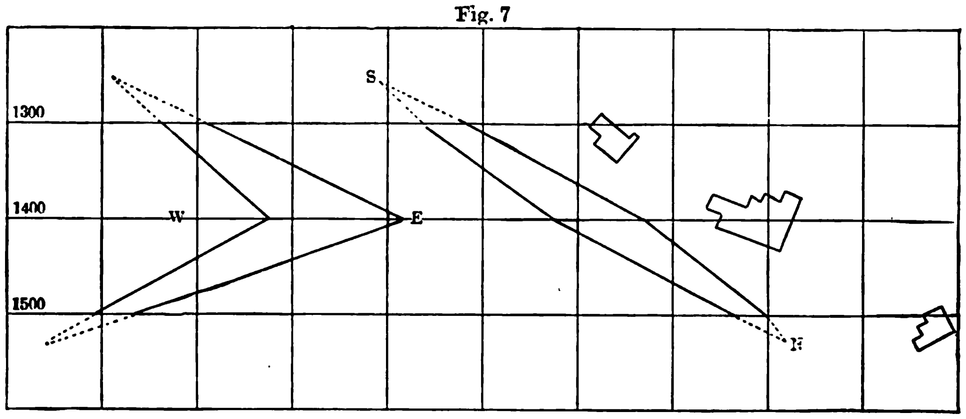
From the sixth section the dimensions decrease in every direction, but the south side of the ore body maintains its vertical position down to the 1550 level where it suddenly ends, and the bottom is reached. Whether the rich ore lies on quartz or on country rock was not ascertained, but the latter is probable.

The small ore body of the Consolidated Virginia lies mainly between the

1300 and 1500 levels, and therefore occupies a part of the ground which has already been shown, in the sections just given, to have an east dip above and a west dip below the 1400 level. It shares this change of inclination, and shows the following section, Fig. 7, when followed down on the axis of the ore; the pitch being so great that a vertical section reaching from level to level cannot be obtained.

This ore body changes its strike in a noticeable manner. On the 1300 the course of the stopes is about N. 45 E., and on the 1500 N. 20 W., the axis veering round 65 degrees. The mass probably has a twisted shape such as would be obtained by lying in the grove of a long-twist auger, and making about one-third of a turn about the axis. All these peculiarities are exhibited in the figure.

Fig. 7



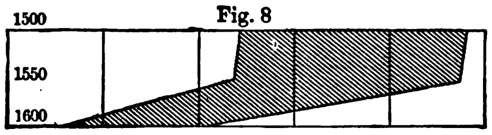
VERTICAL SECTION, Following the Dip.

VERTICAL AND HORIZONTAL SECTIONS, Showing Pitch and Variation in Strike.

CONSOLIDATED VIRGINIA, SMALL ORE BODY.

Scale 200 feet to 1 inch.

Fig. 8



CALIFORNIA MINE.

VERTICAL SECTION OF ORE BODY.

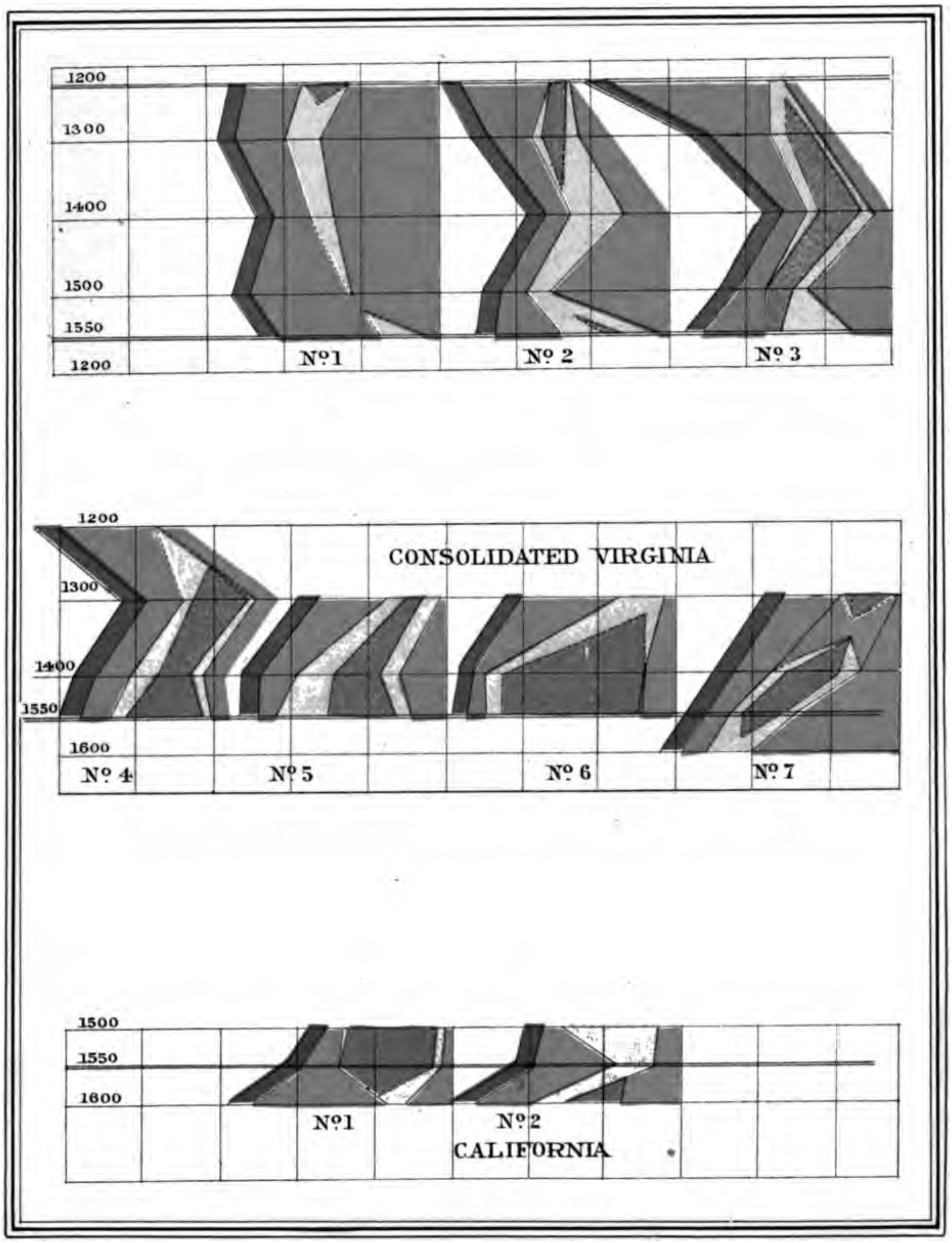
Scale 200 feet to 1 inch.

The California bonanza is not sufficiently extensive in vertical dimensions to give a significant profile when divided from east to west; lying mainly between the 1500 and 1600 levels, its upper and lower terminations are both concealed in the intermediate ground above and below. Still the partial section, Fig. 8, shows that it has the same west dip in its lower extremity, but this occurs on a level 150 feet below the commencement of this west inclination in its smaller neighbor. These sections do not adequately show the source of the vast supplies of ore which have been extracted from this mass, and which are due to its remarkable proportionate thickness.

Looking at this system of depositions as a whole, it will be seen that if it is seated upon a dome-shaped mass of country rock, it must occupy a position similar to that of the 6, 7, 8, and 9 hour marks upon the face of a watch. Following the direction of the dial, it is situated in the third quarter of the circle. Looking at the cross sections it is apparent that it lies on the under side of the dome. It is not merely that the lower termination points westward, which it does not do in all the sections, but in all probability the whole mass occupies that position, and the reader has presented to him in these sections the concrete form of what has been designated a "dome" for lack of a more exact description. Horizontally, the ore body is bent around a curvature of the west wall, and vertically it occupies the descending side of a similar curve. Of true dome shape there is none, but the effects are such as can be explained only by placing the mass upon the third quarter of a hemisphere.

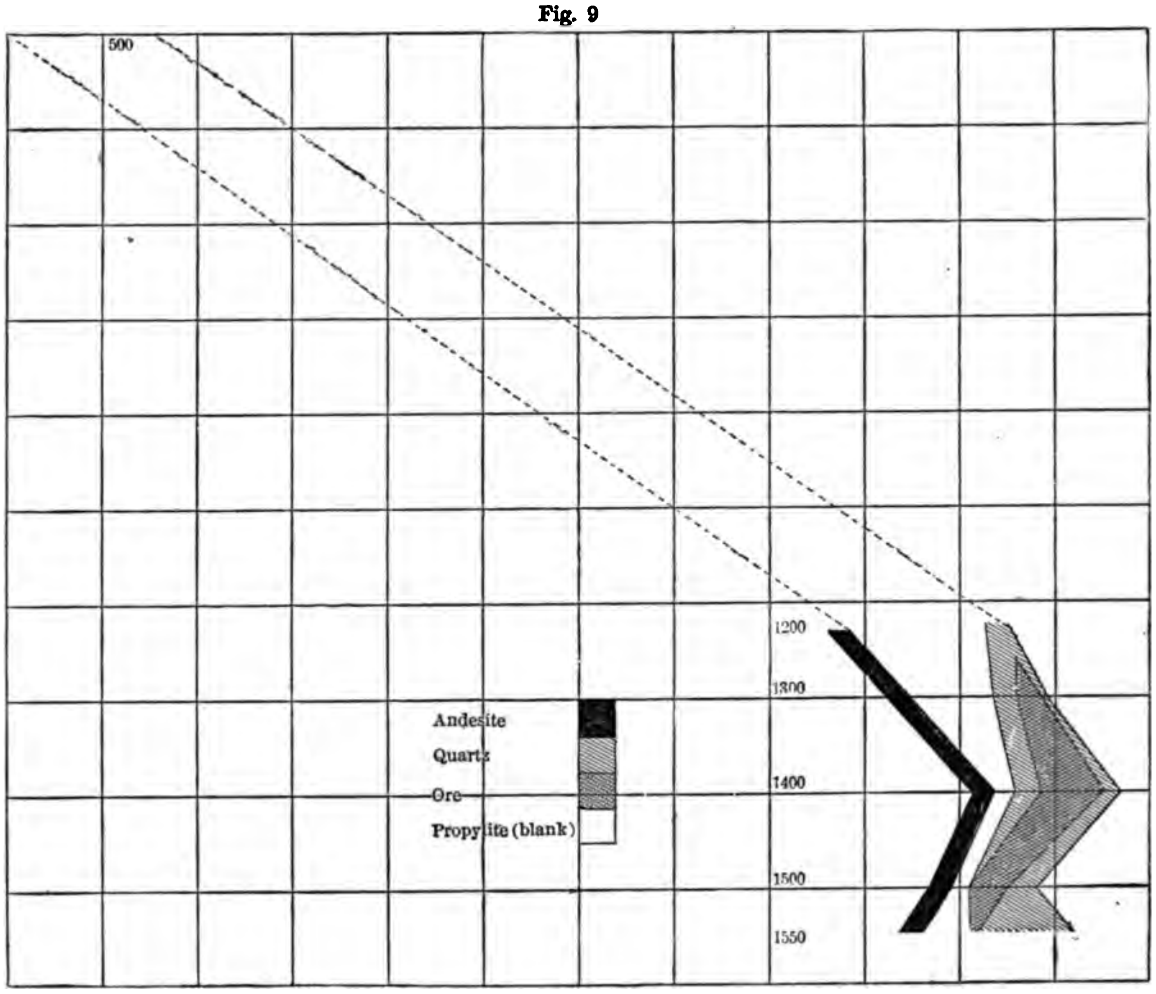
It is to be regretted that the ground in which this ore body was found has not been explored continuously from the surface. It was discovered by exploration from the works of another mine, and no levels have been opened between the 1200 of this bonanza and the 500 of the old workings. On that level the "vein" is shown about 600 feet above, and 900 feet west of the ore streak on the 1200 level. While nothing is known of the course which the quartz takes between these two points, it will be readily seen from the section, Fig. 9, that the bonanzas occupy a more vertical position than can exist in any other part of the ground between the two levels. The position of the 500 is taken from an old map. The section also shows the sharp vertical undulations of the strata in the ore ground, and in these evidences of great pressure we may possibly have the explanation of the extraordinary and abrupt thickenings of the quartz. Where so much disturbance took place, we may safely imagine the existence of crushed strata, and the multiplied crevices of the broken rock would give the siliceous waters every vantage for their work of substitution.

COMSTOCK LODE. VIRGINIA MINES. *Plate V.*

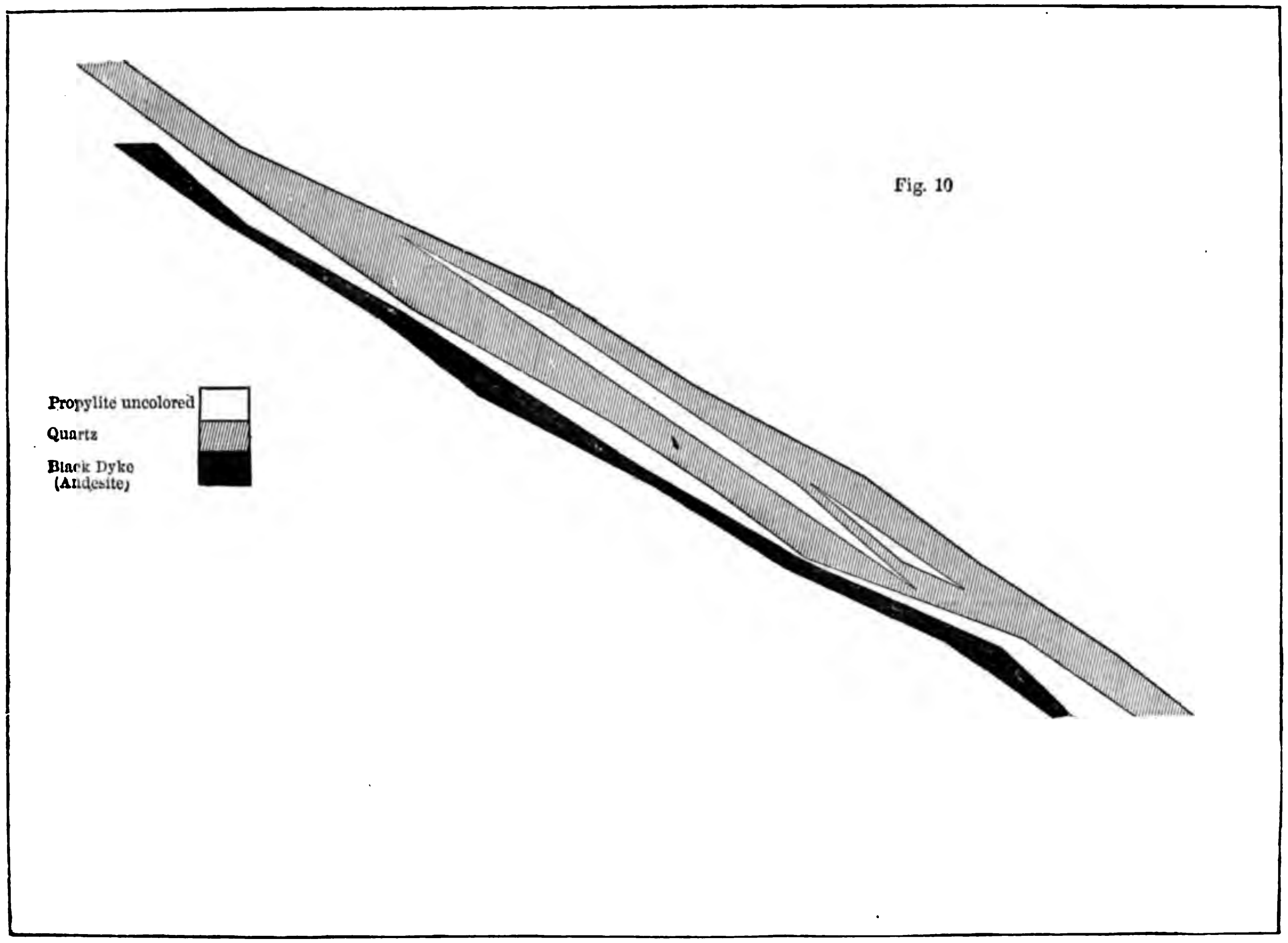


Entirely opposed to the most striking characteristics of the "bonanza mines," the Crown Point and Belcher ore body lies on a gentle slope, having a dip of about 35° from the horizontal. This is just about what the Jacket barren quartz has; and from this comparison it is evident that the preparation for ore deposition has not required one sole degree of inclination for success. It has not been concrete dip, but relative dip that gave room for ore to form, and these two mines obey in every respect the law which is discerned in all the others, that the ore is on the steep dip, whatever that may be.

Fig. 9



CONSOLIDATED VIRGINIA MINE.
VERTICAL SECTION SHOWING AVERAGE DIP OF LODE ABOVE THE BONANZAS.
Scale 200 feet to 1 inch.



CROWN POINT MINE.

Relation of Ore Quartz to Dyke, and enclosure of two horses, forming three ledges.

Vertical Section Scale 200 feet to 1 inch.

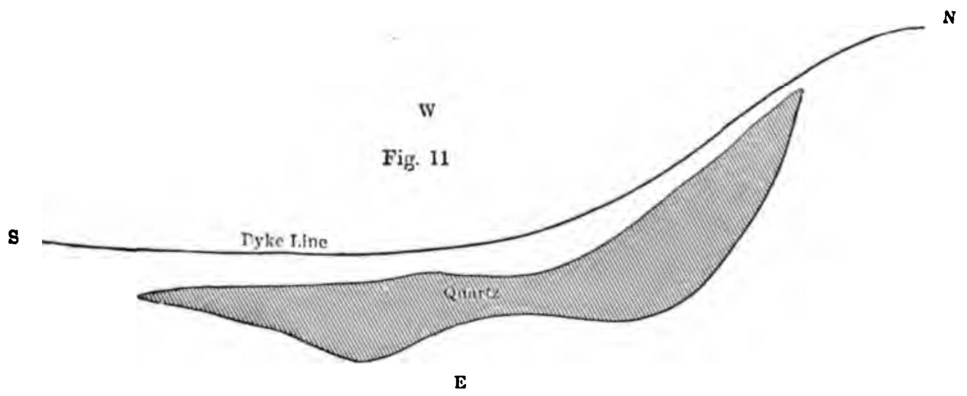
This is well shown in a section of the Crown Point, taken 1800 feet from the northern end of the Gold Hill group of quartzes. The outline, Fig. 10, shows its three grades of inclination, the top being occupied by barren quartz, the middle by the ore body, and the bottom slopes by another mass of barren quartz. Gentle as these slopes are it is probable that this ore body occupies the same position as the great Consolidated Virginia and California bonanzas, namely, the under side of a dome. The decreased inclination of the west wall in the lower levels may indicate that the lode is there surmounting one of its longitudinal folds, having just passed the descending side of another. This section is chosen in order to show the mode in which the unremoved propylite horses divide the quartz, and the change of inclination is not so strongly marked at this point as elsewhere in this and the Belcher mine. At the point where the ore gave out, the walls had a slope of only 20 degrees, but that extremely low inclination continued for only a short distance.

In the longitudinal direction this ore body shows precisely the same characteristics as all the others. It is bent over a curve of the black dyke, has its thickest mass on the shoulder of the curve, and points its northern end straight into one of the troughs of the dyke. In all these points its northern termination closely repeats the phenomena observed in the southern end of the Consolidated Virginia bonanza. But its position appears to be slightly different. While the latter occupies the third quarter of the circle, the Crown Point and Belcher body appears to be planted on the second quarter of a much flatter dome, which allows its quartz to penetrate for 1000 feet into the partings between the strata upon its crest.

The relative position of the dyke and the quartz is shown by the outline, Fig. 11, taken from the 1200 level. As a whole, this bonanza forms a mass having about the same height and breadth, and lies entirely between the same vertical planes, not showing the pitch which is so marked in the Consolidated Virginia body. It began and ended by simple thinning out, and though it contained three distinct ledges these were laid one over the other in an east and west direction and evidently occupied parallel seams. There was no breaking up into separate bodies north or south of the principal mass, and all the horses therefore obeyed the usual rule and ran in the direction of the strike of the lode.

Finally, we have in the Justice one of the most phenomenal deposits of ore ever found in the Comstock region. References to the detailed description of that mine will show that the ore-bearing ground consists of three divisions. First, there is a thick mass of ledge propylite composed of altered country rock, and having a general strike of about N. 60 W., magnetic. In that lies a large accumulation of mixed calcite and propylite, exactly corresponding to the quartz bodies of the Comstock. This has a strike on the 400 level of N. 30 W., but veers round in descending until on the 800 level it strikes about N. 50 W., or nearly parallel to the decomposed rock on the higher level. This calciferous mass is termed the *ore channel* in this memoir, and is known on the Comstock as the "quartz body" by a pardonable analogy. In this ore channel lies an ore body which on the 400 level has a strike of about N. 30 *east*, and therefore is diagonal to the ore channel and at an angle of 60 degrees from it. Like the mass in which it is imbedded, it veers round in descending, and on the 800 level its strike is about N. 20 W. Finally, on the 1000 and 1150 levels, where it has diminished to a thin seam, it has the same strike as the ledge porphyrite, N. 60 or 65 W. These peculiarities are shown in the plan of the levels, Plate VI.

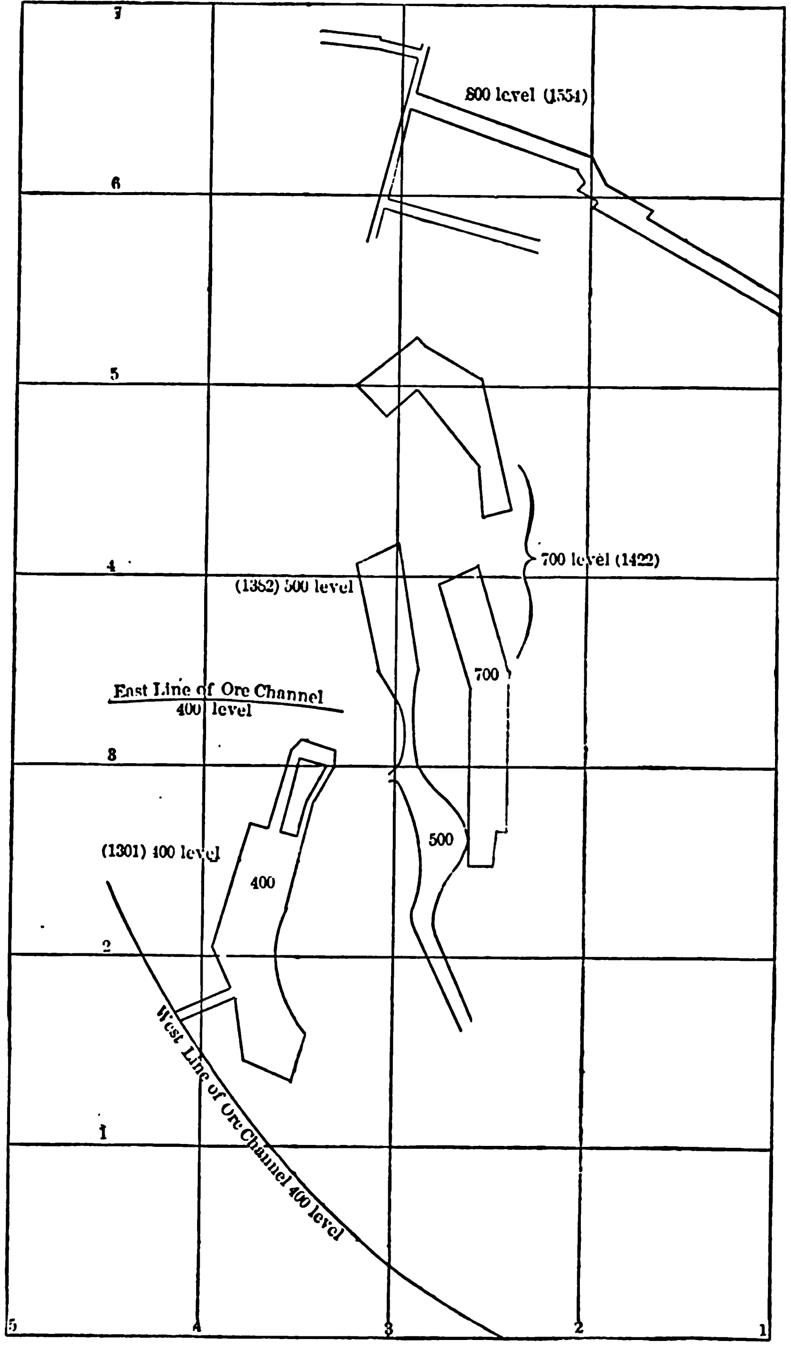
Fig. 11



CROWN-POINT AND BELCHER.
RELATION OF THE QUARTZ TO THE BLACK DYKE.
Horizontal Section.

The depths given here are nominal, their real distance below the mouth of the shaft being 369 feet for the 400, 622 feet for the 800, and 822 feet for the 1000 level.

Fig. 12



JUSTICE MINE.

POSITION OF ORE STOPES 400 TO 800 LEVEL.

Scale 100 feet to 1 inch.

Like the ore channel the mass of this ore body is composed of calcite seams of all thickness up to eight or ten feet, disposed between layers of unremoved propylite, faced by seams of blue clay. No other discovery made in the Comstock region of late years departs so widely from the established rule of the lode as this ; but its peculiarities are probably to be attributed to proximity to the surface. The shape and relative positions of the stopes on four levels are shown in the outline horizontal sections Fig. 12.

There is a bend in the Justice dyke in this part of the claim, but it is not strongly marked, and seems to be confined to the neighborhood of the surface, for below the 800 level the strata are not found to be curved. Even if the ore channel were proved to bend around a curve in the dyke, it is apparent that the ore body, lying sharply across it, could not do so. In fact, it abuts square against the line of the dyke, and about 175 feet from it on the 400 level.

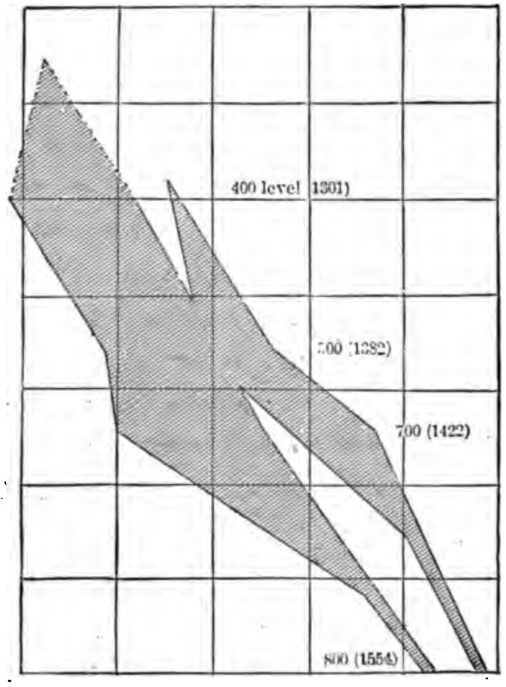
In this position it is inevitable that the mass of rich ore cannot follow the seams of the strata for more than about 30 feet, which is its *length* measured in the direction of the ore channel, in the upper levels ; while its *thickness*, measuring in the contrary direction, is 130 to 250 feet. The lower of these measurements is that of the 400 level, and the higher is taken in the 700 level, which is 121 feet lower down. Here and also on the 800 level there are two ore bodies, and this appears to be true on the 400 where there is a small seam of about 10 feet thickness, 40 feet east of the main body. But there is no sign of this on the intermediate 600 level, though here the main mass is 30 feet longer than on any other level. It is probable that the division of the ore into two bodies extends through the whole height of the stopes, with perhaps sufficient ore in the intervening horse at one point to make its extraction worth while.

The exhausted stopes were not in a condition to allow examination, which was attempted ; but the shape of the ore, as shown by plotting its greatest east and west dimension on each level down to the 800, is given in the vertical section, Fig. 13, p. 127.

This section is necessarily deceptive, because the *length* is given on three levels, and the *thickness* on one. Taken across similar dimensions, the section would show a maximum thickness of about 30 or 35 feet on the 400, and two seams of eight or ten feet each on the 800.

There can be little doubt that in these singular phenomena the Justice merely repeats the history of the Comstock in its upper levels. There it was a true fissure vein for the most part, and its ore seams sometimes bid defiance to the west wall, and took up a position quite as anomalous as this in the Justice. One of the Savage bonanzas, as figured in Mr. King's atlas, Plate II., showing a level 625 feet below "Point A," is a case in point. Like the Justice body it abuts against the west wall and at a distance of about 100 feet from it. The explanation is doubtless the same in both cases. The movement of the ground resulting from the weight of the trachyte abandoned the lines of stratification as it approached the surface and cut through them. In the description of the Justice it will be found that this effect has been continued to the lowest level worked (1150), thus giving to the lode the characteristics of a true fissure vein for the whole of its known depth.

Fig. 13



JUSTICE MINE.

VERTICAL SECTION OF ORE BODY.

Scale 200 feet to 1 inch.

CHAPTER VIII.

SUMMARY.

THE story of the Comstock is now completed, and nothing remains but to find the conclusions to which it naturally leads. It has not proved to be what was anticipated when the survey was undertaken. The overwhelming catastrophic accidents to which the production of the lode has formerly been assigned have given way to successive orderly movements regulated by laws which are discernible all over the earth. But perhaps the principal value of the Comstock in a general sense is the opportunity it offers for giving definiteness to the vague terms to which the geologist is usually driven in describing the forces which have produced vein structure. "Force," "rupture," and similar general phrases are usually employed to indicate causes which can rarely be more precisely defined. But the evidences in the Comstock region point directly to the origin and method of the action. No quartz was introduced into the rocks there until after the loading of the surface by an enormous weight, and no ore appeared until after the placing of a second huge mass upon the edges of the strata. This is a field where well understood forces have acted harmoniously, and the immense results do not seem astounding when compared with their causes. The order of events will be more readily understood by summarizing the principal facts that have hitherto been discerned. They arrange themselves into a regular succession of periods and subordinate epochs.

FIRST DYNAMIC PERIOD.

1. *The Diorite Epoch.* The horizontal deposition of the diorite in stratified layers by a series of eruptions, and no doubt from a succession of fissures, the position of which is still unknown. (See Note on p. 57.)

2. *The Subordinate Pressure.* The system of diorite strata was acted upon by a pressure which produced broad folds with east and west axes, an uplift in Virginia and a trough in Gold Hill, the elevation being much inferior to

the width of the curves. This important force continued to affect the rocks through the greater part of their history, and is the dynamic cause of the lode.

3. *The Propylite Epoch.* The horizontal deposition of the propylite, also in stratified layers from successive fissures. The new rock may be somewhat uncomformable to the diorite, but its members are essentially parallel to the older layers. This system of strata was also moulded by the subordinate pressure ; but the new folds are much less prominent than those in the diorite, and also do not correspond with their broader features, no trace of the great Gold Hill trough being visible in the arrangement of the propylite so far as it can be made out. In the region occupied by this diorite trough the propylite has a succession of independent moderate folds, the undulations of which now form the seat of the lode in that quarter.

4. *The Principal Elevation.* After the propylite, came a movement by which the two series of eruptive depositions were raised into a mountain system, the summit of which is now the Virginia range. This elevation took place about a north and south axis, and its folds are therefore at right angles to those of the former movement. They are greater in altitude than those in the opposite direction ; but these grand elevations show no sign of having affected the fortunes of the lode in any important way. Upon the slope of the principal elevation are low waves parallel to the principal crest, and it is the forms given by the subordinate pressure to these lesser undulations that in a later epoch determined the position of the quartz bodies. In a similar way the details of surface geology have been controlled by the effect of the principal elevation upon the larger subordinate folds which already existed when it began to act. Where the Virginia uplift (subordinate) surmounts the crest of the main elevation stand Mounts Davidson and Butler, the highest summits of the range, and here the diorite protrudes through the eroded propylite, giving the only important exposure of the former rock in the whole region.

5. *The Andesite Epoch.* A third period of eruption follows, the seat of which is in the upturned strata of the diorite and propylite. These are not fractured, except near the eroded surface, but the layers are separated, and the andesite rises through the crevices, establishing an extensive system of bedded dykes. Some of these exceed 100 feet in thickness, and the total section of the dykes lying within view on the eastern slope of the range is probably be-

tween 1000 and 2000 feet. The number and size of these dykes indicate eruptions of immense magnitude, the probability of which is further sustained by the existence of widely scattered patches of andesite at various heights. The whole mass is assumed to have been some thousands of feet thick, and to have played an important part in the history of the lode by its weight and rigidity. In the immediate neighborhood of the andesite dykes the propylite is shattered by the heat of the new eruption for a few feet in thickness. These deep-reaching zones of fissured rock subsequently became the channels through which siliceous and metalliferous waters rose to the lode.

6. *The Opening of the Strata.* The grand elevation which formed the mountain range seems to have been finished or nearly finished before the eruption of andesite, but the subordinate pressure producing the east and west folds continued. The crests of folds already produced were lifted forcibly against the rigid andesite cap, while the intervening troughs were bent downward, relieving them from its weight. Under this action the uplifted portions of the strata were squeezed sidewise into the relieved troughs, opening slightly the partings between the layers. This opening took place mainly in the troughs, and the parted seams form lines of communication extending sometimes for thousands of feet downward. All of these systems of parted seams are curved, and one end of the curve points toward and lies near one of the andesite dykes.

These movements finish the first and greatest of the dynamic periods. It is followed by a period of chemical action.

FIRST CHEMICAL PERIOD.

7. *The Siliceous Epoch.* Through the small partings of the strata thus opened in the troughs of the subordinate folds, rose currents of water holding silica in solution. The strata subjected to their action were dissolved or carried off mechanically, and quartz with "base" metals was deposited in their place. This action went on in each of the open seams, the intervening rock being attacked from both sides until the meeting of several depositions of silica composed quartz bodies which in many cases had a thickness of several hundred feet. Their linear extent was further increased by the percolation of the waters into the closer

rock partings, and the establishment of thin quartz seams in the continuation of the open crevices. This quartz is not argentiferous and no ore was formed.

A second important result of this appearance of siliceous waters is the almost entire removal of the immense andesite cap, which was decomposed in the same manner as the deeper lying rocks, being transformed to clay, and carried off on the current. The tremendous results of this period of chemical action, as shown in the accumulation of quartz by hundreds of millions of tons, indicate that the water came in great quantities and through a very long time.

SECOND DYNAMIC PERIOD.

8. *The Trachyte Epoch.* The second dynamic period was then entered upon. New crevices opened in the eastern part of the district and vast floods of trachyte poured out, covering the whole Comstock region precisely as the andesite formerly did, though the centre of the later eruptive deposits is considerably to the east of the older centre of deposition. In spite of extensive erosion the trachyte still forms lofty hills rising 1200 to 1300 feet above the propylite at their base. The immense mass and weight of the andesite were repeated by the newer rock, but with different effect upon the lode. Producing instead of resisting movement, it loaded down the hanging wall of the lode so heavily that it slid upon the foot wall. By the ordinary law of such movements the hanging wall moved upon those parts of the quartz bodies which are the least inclined, while the walls were torn apart in the steeper portions and new crevices opened there. An entirely new system of openings, precisely similar to the first, but in a different position, may also have resulted from the weight of the trachyte. Wherever the subordinate east and west folds were broken through by the troughs of the principal elevation, one side of the troughs would stand at a very steep angle. There the downward movement might open the partings between the strata, and new quartz bodies, entirely post-trachytic could be laid down by a repetition of the process of substitution. Near the surface the new crevices abandoned the old line of quartz deposition and broke through the hanging wall vertically and in directions which sometimes overpassed the perpendicular and gave a west dip to these fractures. This portion of the lode therefore presents the conditions of the true fissure vein in its ore-

bearing quartzes; but the resemblance does not extend below the junction of the trachyte crevices with the line of pre-existing quartz masses.

SECOND CHEMICAL PERIOD.

9. *The Argentiferous Epoch.* Into these new crevices in the quartz poured a second stream of water containing minerals in solution, but differing from the first in holding not only silica but also silver and gold. These substances were deposited in the reopened portions of the quartz. Where there stood a large deposit of silica already formed, the whole mass was somewhat enriched in the neighborhood of the new crevice, and where the amount of deposited quartz was small or where the reopening of the ground was wide, a richer ore was produced. A similar formation of rich ore took place in the new partings spoken of. It is possible that insignificant remains of this metalliferous flood are to be recognized in the existing hot waters of Steamboat Springs, which deposit a siliceous sinter that has been reported to contain a little cinnabar and even gold.

The facts here brought forward are of the utmost importance, both to the future fortunes af the Comstock lode and to the general theory of mineral veins. They show that no vein and nothing like a real vein exists in ground that has for years been supposed to contain the boldest example of true fissure vein formation in the world; that the largest bodies of ore can be formed from deep sources of mineral supply without the agency of a fracture even of the smallest dimensions; and that it is quite unnecessary to seek for great dynamic convulsions to account for the formation of thick masses of ore within the solid rock, a sufficient cause being found in the quiet action of the same forces which have everywhere moulded the crust of the earth. Though no vein can be found, the quartz is certainly not segregated. The masses of ore matter are entirely different from the surrounding rock, which could not have produced them either by yielding up mechanically held silica, nor by any known method of mineral decomposition. They are altogether foreign to their present *habitus.* They do not fall into the existing systematic definitions of ore masses, for while they have the position of segregations, they are more widely separated from this class of bodies than from any other. They have the deep origin of the true fissure vein, but do not exhibit the smallest continuous crevice.

Instead of being the product of formidable convulsions their history has been one of almost perfect calm, and they have witnessed none but the gentlest kind of movements. They are the product of the slowest possible incubation, and have not the first sign of catastrophic birth.

Such conclusions are especially novel when applied to ore bodies lying exclusively in eruptive rocks, but they are borne out by the study of the ground.

In this view the true fractures practicated in the hanging wall near the surface are regarded as secondary occurrences, foreign to the general mode by which the lode was formed. They are not repeated anywhere below the first 500 feet of depth.

To admit the Comstock lode into the existing systems of metalliferous deposits it will probably be necessary to widen them by introducing a class of *substituted masses*, formed by replacing portions of the mother rock by minerals brought in from a source extraneous to the locality of deposition. We already have segregated masses produced by infiltration of minerals derived from the rock in which they lie, but these are entirely local and do not have the deep origin which the ore of the Comstock certainly enjoys.

If the Comstock is not a vein, the problem of determining what it is becomes very important. To settle it we must turn our eyes away from the single line of quartz bodies which has been the subject of our consideration hitherto, and bring within our view all the depositions in these rocks which have the same geological history. We must raise our speculations from the Comstock lode to the Comstock system of lodes. In this view we have a series of stratified eruptive rocks, say 12,000 feet thick, in which lie a great number of large quartz masses, disconnected and yet not distributed at haphazard through the rocks, but occupying definite positions on several regular lines.

One of the most important deductions that can be made from this theory of the lode is that in the absence of fissures reaching to the surface there may be ore bodies imbedded in this great series of eruptive strata, which show no trace of their presence at that level of the propylite which is now cut through by the surface. The masses of quartz are so completely isolated that no one would think of prospecting the barren ground above them except on the two lines which have already been explored. In the Comstock, erosion left the surface line at a level where there was a zone of extraordinary richness; but if it had swept away about 2000 feet more of the rock, the existence of a vein in Gold Hill might not have been suspected, and hardly perceived even in Virginia. From the Bullion to the Caledonia, a distance of more than a mile, there is between the 1500 and 2200 levels a zone so barren that the works prosecuted in it have been sustained only by the knowledge of the sound character of the great lode in which the mines lie. Not a ton of ore has been found there; and if this were at the surface level, there might be some indications of a vein, but hardly enough to sustain hope in a land of such great expectations as Nevada.

The fact that even the indications of a vein may be hidden under such circumstances is proved by the failure to discover by surface survey more than four lines of andesite croppings, when there are probably a score or more dykes of this material in the region.

It is not then absurd to surmise that in addition to the known lines of quartz deposits there may be some unknown ones the faint outcroppings of which are concealed by the shingle and decomposition of the surface. The determination of this and similar possible facts in this district cannot be made until the Sutro Tunnel section receives proper study.

In any event the known lines of ore deposition and the number of comparatively small quartz seams running in various directions, should teach us to regard this whole district as one which may in future support very widely extended mining operations, and perhaps a metallurgical industry of much greater scope and complexity than it does at present.

CHAPTER IX.

CONSIDERATIONS WHICH AFFECT THE COMSTOCK.

The search for bonanzas. From the facts presented, it is possible to indicate the conditions which a successful search for ore bodies must, wittingly or unwittingly, satisfy. The search must be prosecuted in two directions, eastward across the strata and downward on the dip. The former must be carefully done, for the reason that the ore bodies do not lie within definite walls, nor do they always approach the black dyke at their upper terminations. In a given mine there may also be a second quartz or ore body outside of one near the dyke and overlapping it, the presence of which could not be learned from any exploration along the dyke in that mine, though it might be discovered by the works in a neighboring mine.

This search across the strata is already conducted with extreme thoroughness in the Comstock mines. At depths of existing works the mode of "winning" or opening the ground is practically by inclined shafts on the lode, from which at regular intervals of fifty to three hundred feet a drift is run north and south to the limits of each mine. Taken together, these drifts form an almost continuous gallery from the Utah southward to the Caledonia, a distance of more than 18,000 feet. From this base crosscuts are opened eastward, and the thoroughness of the exploration depends on the proximity and length of these crosscuts. The length seems to be always sufficient and even more than is positively necessary in most cases. The number of the crosscuts is also great enough usually, though instances are known of large bodies of ore having been passed and discovered subsequently by accident or more complete exploration. The Comstock system, on the whole, is admirably adapted to the ground in which it is applied. It is most apt to fail when small seams of rich ore are found in some huge body of barren or poor quartz. Then the system of crosscutting is apt to be abandoned for the old method of following the ore through all its windings, but as it is quite possible that such a thick mass of quartz may have reopened in more than one place, and the different localities may be entirely unconnected, perhaps parallel to each other, or overlapping, the following up of one ore seam will not always lead to the other.

The search in depth is far behind that across the strata in precision and intelligence. In fact, it is entirely haphazard, and the mining operations show no sign of being laid out so as to take advantage of any series of contingencies. To be plain, there is no true exploration in depth on the Comstock, systematic information being gathered entirely from the levels, and these are not always opened so as to give the facts which are necessary to predict the chances of the next level below.

What these important facts are is plain enough from the theory of the lode as previously explained. The ore bodies lie in the steeper parts of the dip, and for that reason it is necessary to ascertain the variations of dip on each level, and note when a change is beginning. The other important fact is that the thickest parts of the quartz lie on the edge of the hollows of the west wall. It is evident that both of these necessary points of information are to be obtained only by watching the west wall, which is the only constant wall the lode has. The black dyke is, for purposes of exploration, the all-important member of the lode rocks. When its dip increases by more than the ordinary local fluctuations, the miner may hopefully look for developments, and if the steeper dip is very pronounced, or continues downward for any considerable distance his chance for getting them should be excellent. The sinuosities of the dyke in a north and south direction are important, for the position of crosscuts three and four hundred feet apart, as they often are when a large mine has long been in unproductive ground, is of the greatest moment. The situation of the thickest parts of most bonanzas in or near the troughs of the black dyke, points to such places as more promising for exploration than the broad top of the ridges between these troughs. It is to be remembered, however, that the real bonanza lies less in the depths of a trough than on the shoulder of the curve that forms it.

There is another consideration to be attended to, and one on which I can give little information. One of the first requirements of successful search in depth is, not merely to ascertain the presence of ore, but to obtain the earliest indications of it. No guidance can be had in this matter until pains are taken to record the form of the bonanzas in their upper terminations. So far as observed, their upper limit varies in form and position. The Crown Point and Belcher bonanza was highest in the centre, where it showed not a point, but a long uneven line. The Consolidated Virginia bonanza, so far as worked out at the time of this survey, seems to have run upward to a point at its southern end. The difference between these two forms may be due to the great difference in dip and shape of the dome, or to the fact that one was probably formed on the north side while the other was formed on the under or east side of a dome but with a tongue reaching up the south side. This subject of shape has the highest importance, for the position of the uppermost point in the ore quartz may be found to indicate whether the quartz belongs mainly to the first chemical period, in which case the ore would not be so rich as if it could be shown to belong entirely to the second period of deposition.

When a mine is in borasca and no ore appears for long distances, the opening of levels near together, with their crosscuts, often amounting collectively to thousands of feet in length, is very expensive, but no mode of evading the necessity has been found, except to sink a few hundred feet at hazard, without exploration. But with the knowledge that the lode carries ore bodies only in its steep dips a more rational system is possible. When the lode is barren, the shaft can be carried down without much exploration, so long as the west wall is found to keep on its flat dip. If that covers a depth so great that exploration is deemed advisable at any given points upon it, the works can safely be confined to the west wall, and when the position of this member through the whole length of the claim is ascertained and compared with that on the levels above, the conditions of the lode at that point and the prospect of its carrying ore should be known, with little chance of error except in the case of an overlapping body which reaches the black dyke in a neighboring mine. The saving of time and of labor by this system would be greatly increased by the saving of pumping expenses which stand in a nearer proportion to the amount of crosscutting through the east rocks than to any works which are opened in the quartz. With this system the whole task of careful exploration can be concentrated on those portions of the lode which are really promising.

The depth of the lode. If the Comstock is not a true fissure vein and does not owe its existence to a disruption of the rocks by a force that operated from some point seated deep in the crust, the probability of its being continuous to a great depth becomes a prominent question. Under the explanations here given, our views on this point must be determined by comparing the force at work with the materials upon which it operated.

In a few words, the force is pressure (very possibly of contraction), the extent and power of which are indicated by the fact that it has operated through the whole of the diorite, propylite and andesite periods. When the true thickness of these rocks is known, it may be possible to fix limits to the depth of the lode, but at present the discussion is necessarily confined to that portion of the series which includes only the last of the diorite layers, and the whole of the propylite and andesite. This series will be taken at a minimum thickness of 12,000 feet.

We have then a mass of stratified rocks 12,000 feet thick, the whole of which have been affected by this pressure, as the presence of large quartz bodies in horizons widely separated proves. This mass of strata has been uplifted by another force, distinct from that which formed the lode, and it is thrown into great folds, of which the Virginia range is an uplift with its down-throw extending toward, and perhaps under, the Carson River. Inasmuch as the whole of this mass has been moulded by the lode-forming pressure, the probability is that the formation of quartz bodies continues through the whole surface area of the Virginia uplift. We may expect to find them as far to the east as the influence of the andesite cap extended, and while those limits cannot now be fixed, there are no indications which would lead us to place them nearer than the Carson, four miles from the lode. For present purposes we will imagine the formation of the lodes to be confined to a system of tilted rocks, 12,000 feet thick, 24,000 feet long, and covering a base 20,000 feet wide. In the lower members of the system lie the present Comstock quartzes.

The difficulty of ascertaining the true average dip has already been mentioned, but if this is assumed to be thirty-five degrees the depth of the black dyke at the Carson would be 14,000 feet, and its length on the dip would be about 30,000 feet. It is probable that the seam of shattered rock which was produced by its heat continues through all that distance, and we may conclude, on that ground, that the dyke vein which was formed in this seam has an equal extent. And it is obviously possible that ore bodies may have formed at any point in this great depth where the behavior of the strata, under the double influence of pressure and weight, opened the ground for the entrance of waters from the dyke vein. The whole question of probability is concentrated on two factors.

First, was the andesite cap able to alter the conditions of pressure at this depth as it had nearer the surface, or was the weight of this body, added to the weight of several thousand feet of propylite, sufficient to prevent any movement whatever under the subordinate pressure at great depths?

Second, at what depth did the introduction of silver and gold into the waters take place?

Nothing definite can be ascertained concerning either of these questions. It is impossible to decide positively whether the strata have been opened and received depositions of quartz at all depths, or the action upon them has been confined to a certain distance from the surface where the influence of the andesite cap was felt. The answer to this must be left to the practical miner, but it is quite safe to say that such tremendous pressures as these rocks show the effects of could not be confined to any shallow depth. At present the mines are about 2500 feet deep, and there can be little doubt that their productiveness is likely to continue through at least an equal depth more, and probably 7500 and 10,000 feet of strata would be as readily controlled by the great forces which have been in action here, as the 2500 feet which have been explored. Ore bodies may be less numerous at these great depths, the strata perhaps yielding less readily to pressure, but they probably exist there. In other respects the lode is likely to exhibit the same disposition to arrange its rich and barren portions in horizontal though irregular lines, as in the upper levels, for this orderly succession is not the result of chance, but of the controlling influence exerted by those low waves which wrinkle the broad slope of the main elevation. They were there before the andesite came, and they necessarily resolved the dips into classes; a low inclination on the upper or west side of a wave, and a steep dip on the east or lower side. In the former situation barren ground is found, while the latter opened under the weight of trachyte and is now charged with ore quartz.

The second question is distinct from the origin of the quartz, which in the absence of evidence may be assumed to have as deep a source as the andesite. But the introduction of precious metals does not depend on the appearance of that rock, but on that of the trachyte, and of this member of the series very little is known. Probably it forms bedded dykes like its predecessor, but the first of these dykes is two or three miles to the east of the first andesite dyke. While the latter rock lies among the lower and middle strata of the series, the trachyte occupies the crevices of the upper strata only.

It has been said that the elevation of the Virginia range has a corresponding down-throw in the direction of the Carson. At some point in this trough there must be true fractures extending down to the origin of the andesite and trachyte. These fissures must lie at a considerable distance eastward, for no fault has been discovered in any part of the eruptive rocks. The progressive eastward appearance of the dykes is explainable on the supposition that these fractures propagated themselves higher and higher in the inclined stratified series, so that the point at which bedding took place would be more and more toward the east as the higher strata outcrop in that direction. Under such circumstances the trachyte fissures must have risen still higher through the strata than those of the andesite, and this accounts for their eastern position.

The only deduction that can be made from this reasoning is that the shattered sheath of the black dyke and its neighbors, in the lowest portion of the stratified series, would be the *first* free channels offered to the ascending water. If the latter is under pressure in the interior, the rush through these first openings which it found, *i.e.*, the westernmost, might be greater than anywhere else, and the metalliferous deposition consequently most extensive in the crevices connected with them. Still, though the eastern lodes, of which there are two or three, have never yielded such rich ore as the Comstock, they have also never been worked enough to prove that they do not contain it anywhere in depth.

The Parallel Quartz Bodies. It has already been said that the whole series of Comstock rocks, diorite as well as propylite, contains several lines along which large quartz bodies have been deposited. One or two of these lines are within a thousand feet westward from the Comstock, and probably there is one in this direction that is quite near. Still further on the western slope of the Virginia range there have been openings made and quartz reported. To the eastward there are two important lines of quartz, the Monte Christo and Lady Bryan. These form a magnificent system of quartz bodies parallel to the main lode, and, so far as they have been examined, quite equal to it in magnitude. Under any circumstances they are worthy of careful exploration, especially now that their fortunes have been greatly improved by the construction of a deep drainage adit. Every point that has been made in this memoir applies to them with all the force it has for the Comstock. They lie in the same rocks, were formed in the same way, apparently at the same time, and have been subjected to the same forces and influences. They have passed through the period of argentiferous deposition as well as that in which only quartz and base metals were laid down. Geologically they lie both above and below the great lode, and all the evidence shows that they are essentially contemporaneous with it, though the introduction of a large proportion of lime into the eastern lodes, with the quartz or subsequent to it, indicates either some difference of origin or a difference in date. Probably the latter is true, and these lodes may belong to a later stage of the chemical period. They occupy the same position to both the andesite and the trachyte. All the known geological facts make them just as good ore carriers and just as promising quartzes as any the Comstock contains. Many of them have been tried by mining works and often of considerable extent, but without success. They are known to contain ore which will become valuable when the cost of mining is lower, but is profitless at present.

In spite of this practical failure he would be a bold man who should say positively that these "outside" quartz bodies are uniformly poor. That may be the case, but the irregular and haphazard system of exploration to which they have been subjected does not prove it. There may be important differences between them and their rich neighbor, but these differences have not yet been disclosed, with one exception. The Comstock was rich at the surface; they are mostly poor, or of only medium yield there. But that was also the case for large reaches of the Comstock, and had the surface been cut down to certain levels the existence of the great silver lode would have been almost unsuspected. Barren ground along certain lines is no more proof of the absence of ore in one of these lodes than in another.

In addition to the parallel lodes there are in the southern portion of the field a number of dykes and veins running in various directions, many of which are known to be metalliferous to some extent. They appear to occupy crevices in the mass of metamorphic rocks which that part of the ground contains, but the absence of deep exploration upon them debars us from obtaining the necessary information to give them their proper value. Still, they may form a reserve which will at some distant future day become available and valuable.

Future Yield. The continuance of ore bodies at great depths has already been indicated as probable. As to the yield of quartz lying in the lower levels, it is more likely to be precisely what it has been than to alter. There is no reason why the folds upon which the quartzes lie should differ essentially in shape or size from those above, except that the upward pressure against the andesite may have been more completely taken up by the more numerous clays and cellular portions, and the closer fitting together of the thicker mass of rocks. The pressure was uniform while the conditions under which it acted were altered by the greater depth. This cause may also have affected the distance to which the strata slid upon each other under the weight of trachyte, and thereby it may have lessened the separation of the walls in the steeper inclinations.

It is with reluctance that an opinion is ventured concerning ground the condition of which is totally unknown, and is not even hinted at by the observations made at higher levels. But remembering that the preparation for the deposition of quartz belongs to the period of pressure, the deduction would be that the quartz bodies *may* be of smaller size in the lower levels, because the partings of the strata may have been less opened by the pressure; while the ore *may* be richer because the vertical sliding in these consolidated rocks would be greater than when there were great masses of quartz to partially take up the movement by their consolidation. In fact, while the *quartz* may diminish, the *ore* may really increase, both in quality and quantity.

These remarks, it is repeated, are mere guesses, placed here to show that though nothing is known of these lower depths at present, it may be possible by further study to form a reasonable conclusion concerning the condition of the strata there. All the positive information extant does not warrant us in going further than to say, that the strata, so far as they have been explored, indicate the continuance to much greater depths of all the causes which have combined in producing the ore. There are even signs that a stage of general productiveness may not be very far distant.

The Zonal Arrangement. Hitherto all attempts at grouping the bonanzas have been concentrated on efforts to show the vertical direction of the mineralization. While these have failed, there are evidences that there is a certain horizontal arrangement and that it, like all other orderly features of the lode, is dependent on dynamic action. In this case it is not the subordinate but the principal pressure that has produced the results.

For some years the Comstock has been barren except at one or two points, and the probability of finding ore in depth has been anxiously discussed. The finding of the Consolidated Virginia bonanza was seized upon as a proof that the ore would be continuous in depth; but though I believe this expectation to be well founded, I consider that it has a better basis than the mere discovery of an ore body. The presence of this large area of barren ground may be rationally explained in a way that would indicate the recurrence of an ore-bearing district as a natural sequence to the existence of this barren zone, and indeed in some measure dependent on it. To make this clear it is necessary to review briefly the history of the mines.

The configuration of the surface is so irregular that there are differences in the altitude of the mines on the main lode amounting to a maximum of about two hundred and fifty feet. For convenience of description this may be eliminated by referring all depths to one datum, as Mr. King did, the reference point which he called "Point A," being two hundred feet above the present Gould & Curry shaft. Starting from this altitude we find the history of the lode has been as follows:

From the Sierra Nevada to the Overman, both inclusive, all but three of the mines (Bullion, Consolidated Virginia, and California) had ore in the first thousand feet of depth, and this was above all depths hitherto worked a zone of general production. In fact, there was ore in part of the Consolidated Virginia and California ground. But it was mostly too much loaded with base metals to be available then by milling. Within the second thousand feet only two ore bodies were found, though some of the higher bonanzas continued for a few hundred feet into this zone, as the Jacket, Hale & Norcross, and Savage.

The new bodies were those of the Crown Point-Belcher and the Consolidated Virginia, both of which began about 1350 feet below "Point A," and continued about five hundred feet lower. This second zone of a thousand feet is evidently one of much less general deposition, for its barrenness is broken only at two points.

This change in productiveness is dependent upon a change in the dip of the lode. There is no lack of quartz at this point. Vast quantities of unproductive quartz lie there, showing that siliceous deposition was almost as general here as higher up, but the rocks were not separated by the pressure of the trachyte, and no entrance was possible to the argentiferous waters except at a few points.

Within this second zone there are two occurrences which strike the attention, one in Virginia and one in Gold Hill. In some of the Virginia mines the diorite seems to lie in a flattish table at a distance of about 1700 to 1800 feet below "Point A." Such a table or wide ledge could be formed only by a longitudinal fold parallel to the main Virginia elevation. If the lode follows the contour of such a ridge there should, according to the views advanced in this work, be a series of new ore deposits on its lower side, and the establishment of a new productive zone.

In the Gold Hill mines we are confronted by an extreme thickening of the black dyke, a fact that indicates movement of a kind that may have prevented by anticipation the subsequent opening of the rocks by pressure under the andesite. The result of this thickening appears to be the establishment of a flattening similar to that in Virginia and it should carry similar consequences.

Reviewing the history of the lode in this manner, we find there has been in most of the mines a flattening of its dip in the second thousand feet of depth and that this change has been accompanied by a cessation of ore deposition. According to the explanations given this flattening is due to the presence of a gentle fold with the same strike as the lode, the dip lessening as it rises upon the upper slope of this fold. The contrary state of things will be found as soon as the crest is passed, and a new zone of general ore production is probably to be expected on its under side, *provided* the depth is not so great that the effect of the andesite was neutralized by the stiffness of the crust. That does not seem to be probable for any depth less than five thousand feet as a minimum, and the chances of a second extensive zone of ore production following the barren one and within attainable depths are very good.

There is therefore high promise of extensive future yield, both from the consideration of the probable condition of the rocks in depth and also from the state of things which has been encountered within the barren zone. It is not probable that this great lode is exhausted in any part of its length which has hitherto proved to be charged with ore. Its peculiarities are known and by taking advantage of them the workings can be prosecuted with the best chances of success for a long period.

Ore Channels. A great deal of ingenuity has been expended in efforts to find the precise channels through which the metals have been supplied to the lode, and the fact that the ore was distributed over a large portion of the outcrop along the surface, and immediately below it, but confined to a few points at greater depth, led to the conception of a series of ore chambers widening as they rose through the rocks and attaining their greatest development at the surface. These chambers were supposed to be separated by stretches of barren ground, and the hypothesis in question received a severe blow when the greatest of all the bonanzas, that in the Consolidated Virginia and California mines, was found in one of these barren portions. Still it is quite common to hear it said that there are probably two ore channels, instead of three as was formerly supposed, and it is necessary to show that there are none at all. The metalliferous waters permeated the rocks along a line four miles in length, and whenever they found the rock prepared for them they deposited their burden. It is just possible that the extreme prominence of the ancient diorite ridge which now forms the Divide between Virginia and Gold Hill may have prevented the deposition of quartz for a short distance at that point, a supposition which is the more likely from the fact that the quartz bodies immediately north and south of it have been of remarkable size, even for the Comstock. The existence of an immovable rib in this place might produce a greater movement in the rocks near it under a given pressure. This is equivalent to saying that a common flood of waters was divided by the projecting ridge, making two separate streams. But it is by no means certain that this separation continues in depth. Exploration along this ridge has, it is true, proved its existence for nearly three thousand feet below "Point A," and it is wider below than it was above.

But the characteristic of such folds is to be non-continuous. They are usually interrupted, sometimes giving out entirely, and being replaced by another fold which overlaps them. That may be the case with this dividing ridge in the Comstock, and the geologist might feel quite safe in predicting that it will be found to end somewhere or change its location, and possibly within the limits of mine working. It cannot be looked upon as a wall of country rock absolutely dividing the channel in two. One proof of this is the constant discovery of quartz on this rib. The first siliceous waters made their way there, but the ground does not seem to have re-opened under the weight of trachyte.

The theory of "chimneys" and of fan shaped ore bodies and ore channels must be given up. The developments in the second thousand feet of depth not only do not sutain them, but introduce new and much more instructive forms as the law of the lode.

In considering these remarks it is to be remembered that the east vein of the upper levels was a *true fissure vein* down to the point where it joined the eastward dipping Comstock. Its conditions were therefore different from those which are found in that part of the depth where no fractured fissure exists, and it is not denied that occurrences may have been found there which are entirely foreign to the generic character of the lode in depth.

The Divide. There is one part of the Comstock which possesses especial interest from the fact that it contains the only ground which has never yielded ore. This is the great rib just mentioned, which on the surface forms a spur from Mount Davidson separating the towns of Virginia and Gold Hill, and locally known as the Divide. Its continuation in depth has already been spoken of, forming a rib which cuts the lode in two and giving the only semblance to truth which the theory of detached ore channels enjoys.

On this rib are situated the Imperial Consolidated, the Bullion, and the Potosi mines, and probably there are none on the whole length of the Comstock which at present suffer such doubtful prospects as these. The Bullion has never had ore, the others had it near the surface, and the Chollar-Potosi has in fact only just finished its extraction from the immense bodies of quartz which lay above the 800 level. All of them, therefore, are among those mines which are barren in the second thousand feet of depth, and the two which were productive above have sunk as much as sixteen hundred feet below their rich zone without results. Probably none of the mines are so much discussed as these, and the favorable view of their situation which is taken here does not seem to be shared by many of the practical miners on the ground. Nevertheless, an effort will be made to show that the circumstances do not positively bar them out from good prospects, as so many believe.

Situated on the dividing spur of Davidson their fortunes are closely dependent on its shape and continuance. This is the greatest of the folds produced by the subordinate pressure, and it was probably strongly outlined in the diorite before the propylite appeared. Being merely a fold of elevation we should say, *à priori*, that by analogy with other ridges produced by horizontal pressure, it may be expected to widen and lower its height gradually until it is replaced by parallel ridges, perhaps in the ground of other mines. Or the single bold elevation may be altered into a kind of plateau with low swells upon its surface. Either of these contingencies would be favorable to the introduction of ore into this portion of the ground. The search for ore in these mines has not been carried out in such a way as to make the form of this great rib over which they lie perfectly apparent. But the fact that of the three mines the central one has never had ore while the others have had it above but lost it in depth, is a sign that widening of the ridge in depth is really taking place. This widening is probably accompanied by a corresponding depression of height. If this is the state of things the Bullion is the most favorably situated for finding ore, since the possibility of the great rib breaking up into two lesser ones with a trough between them is not a small one.

The cause of this barren reach is not the failure of a "fissure" to open there, nor a diversion of the metalliferous currents to other quartzes, but the fact that it is situated upon the apex of a ridge, which has resisted the formation of secondary waves upon it. The angle of inclination in this portion of the lode is probably more uniform than elsewhere. The mines which front it suffer not from any inherent incompetence to receive ore in this part of the ground, but solely from a dynamic movement of the rocks, which is entirely unconnected with ore deposition, and one that may at any depth be found to have its limits. If this ridge were as moderate as those which carry the ore in other parts of the lode its probable fortunes might be anticipated with some confidence, but it is the largest and in fact the only example of the kind which has been fully explored, and the observer has nothing to compare it with. No part of the Comstock so clearly indicates the necessity for careful attention to the position and changes of the west wall as this.

The East Clay. The irregularity of the clay seams has always been matter of observation. In the upper levels, where in addition to the regular lode there are local fractures, this diversity of direction amounted to positive capriciousness. Lower down there are still some abnormal dips and strikes among these seams, but on the whole they are so much more regular that their general north and south strike, and east dip is never doubted, but is invariably expected of every prominent or persistent occurrence. These simpler conditions have thrown light upon the origin of these plastic sheets. Many of them lie in partings of the strata which were so slowly penetrated by the siliceous waters that the amount of silica supplied was only sufficient to effect decomposition of the propylite, without the addition of a quartz deposit. Many of those in the quartz bodies apparently mark the point at which the work of vein-making paused for a time, giving the clay time to form against the wall rock which was afterward removed by resumption of the mineralization, the clay being protected by its impermeability to water.

The east clay is especially irregular in strike, its undulations making the nips and swells in the lode. It is common for the miners to fix upon a particular clay on each level as the "east clay," and the crosscuts are continued until this is found. How it is recognized is a question that not even the most experienced of them could answer, and the decision seems to depend almost entirely upon its position, for it presents positively no marked characteristics to distinguish it from others which are passed and rejected. It has already been pointed out that the Jacket east clay lies far to the eastward of the quartz on all the levels below the 1531, hundreds of feet of propylite intervening between it and the quartz. As selected by the miners it certainly carries down with fair regularity the lines of that decomposed mass of propylite in which the quartz lies, and in that respect it is impossible to deny the acumen with which one out of many similar clay seams is selected as the true boundary clay. But are we to give full credence to this assumption of the miners and endeavor to ascertain how it is that this boundary is carried down so singularly through solid porphyrite, outlining a lode which is not filled with quartz?

The question has no practical importance, for the search after ore does not necessarily depend upon finding this east wall, but it is intimately connected with the theory of the lode.

The question just stated must be answered in the negative. The east clay is not a true wall except where it is near the quartz. Its presence in the propylite nearly parallel to the great quartz masses indicates nothing more than the position of one of the opened partings which lay too far from the channel on the dyke to be effectively reached by the waters. In fact, as has been mentioned above, it is not alone but is one of a parallel series lying east of the quartz and occupying seams in the opened partings between successive layers of propylite. The whole lesson of the Comstock is that as a lode it is confined to the quartz bodies, and masses of country rock which lie outside of these limits are not to be regarded as representing the horses of a real vein, where there are definite walls with an intervening space which may be filled with ore or with any other substance. The Comstock lode is composed of quartz masses distributed on a certain line, and where they are absent there is no vein though there may be in the same line sufficient decomposition to guide the miner to the direction of new quartz deposits. Even this, however, may fail, for the true guide is the west wall. Decomposition can be found in numberless localities, but the ore is invariably near the black dyke.

In closing this chapter it may be well to point out one or two errors which have crept into the general comprehension of the phenomena observed in the lode.

Position of the Ore Bodies. These have always, from the beginning of mining operations, been found to have a steeper dip than the barren parts of the lode, and all agree in explaining this phenomenon by saying that they start out from the foot-wall and rise to the hanging wall, or at least tend to do so. As a consequence of this theory, it is usually held that the ore should lie further from the black dyke at the top of the bonanza than at the bottom, where in fact it should run into the dyke. This belief is given as a deduction from theory rather than as the result of observation, for none of the ore bodies which are now in a state that permits examination show facts upon which to sustain it. There is one point at which every ore body in the Comstock approaches the dyke, that point being either the north or the south end. Elsewhere the separation of these two members of the lode is quite irregular and not subject to any discernible law.

As a consequence of this popular impression, it is the fashion on the Comstock to lay great stress upon the distance at which newly discovered ore lies from the dyke, and also upon the steepness of its dip. In some cases the existence of the west wall in the neighborhood of an ore body is not acknowledged for hundreds of feet of workings in depth. According to my observations this mode of treatment is not only unnecessary but hurtful. The largest and best bodies I have been able to study have lain near the black dyke at all depths, and have even been closely applied to it for long distances. Nor do we find that the ore bodies stand at a greater inclination than the lode. My observation is that the west wall and the quartz bodies dip together, but that the latter contain ore only in those parts which are steepest.

Crushing. Another fact which is of course observed by every miner is that the ore quartz is to a large extent in a powdery condition, to which the common name of *sugar* quartz is given. This is invariably explained by the miners, and indeed by all previous observers, as the result of crushing, and gigantic movements are necessarily conceived to account for the results. The difficulty with this explanation is that no movements which the earth is considered to be capable of could crush a mass of quartz five hundred feet high, two hundred feet thick and six hundred feet long, *to powder*. It might grind a thinner mass of quartz and propylite to a plastic clay, or it might consolidate any mass of powder to a firm rock, but movements that would convert seventy per cent of such a body of solid quartz to a very uniform powder, capable of passing through a mesh of eighteen holes to the linear inch, have not yet been satisfactorily conceived. The truth is, the crushing of masses so very thick to this powdery condition is simply impossible. The theory is not borne out by the observed effects of crushing in any other rocks. It is also opposed by the fact that some of the barren quartz bodies of the Comstock, precisely similar to their richer rivals in size, position, and structure, are solid, and the theory in question does not show how they have escaped so completely the effects of such mighty movements.

The thick clay seams sometimes contain spherical masses of quartz a foot or two in thickness. They are entirely inclosed in soft clay and if they were hard it would be utterly impossible to crush them to powder by any power applied to their present soft bed. Nor could they be so completely powdered without an evident change of shape.

The lesson to be derived from the sugar quartz is not that it has been crushed, but that it has been preserved from crushing. It was formed in the state of powder, and since its deposition the lode rocks have not received any addition which could weigh it down. On the other hand, the barren quartz was probably laid down in a similar state of powder, and has been consolidated by the load of trachyte upon the surface.

The granular condition of the quartz in the lower levels is one result of its mode of deposition. That has been its condition always, or at least since the close of the chemical action, and its occurrence is one of the prominent facts of the lode which every theory of ore formation will be required to satisfy. The general appearance of the lode points strongly to an aqueous origin for the quartz, and the granular deposition is perhaps due to the degree of concentration and temperature of the water.

CHAPTER X.

GENERAL CONSIDERATIONS.

Stratification of the Eruptive Rocks. The surveys made for the route of the Pacific Railroad and those more extensive examinations of the country west of the Rocky Mountains which since that time have been undertaken for professedly scientific purposes have demonstrated the existence in western North America of eruptive rocks over an almost incredible extent of territory. The largest accumulations of eruptive material known elsewhere hardly hint at the possibility of such extensive and massive distribution as it has had in this broad area. If eruptions are acknowledged to be convulsive movements, the western part of this continent must have suffered extraordinary throes, and any means of obtaining real information concerning its history cannot fail to possess very great importance.

In this connection the opening of large mining works at several points in rocks of this class must become an event of extraordinary geological interest. We have in the Comstock a series of them penetrated by workings between one and two hundred miles in length, and this in a formation that is so simple in its arrangement that there is no reason why these eruptive depositions should not yield up their complete story to the persistent observer. This work has already received the careful attention of such brilliant and capable geologists as Von Richthofen and King, and it is likely to reward any faithful workman who resumes it.

The present memoir relates the conclusions obtained in examining these rocks from the standpoint of the miner exclusively, and without particular reference to broader geological problems, but some of the facts observed are necessarily applicable to the general geology of the American eruptive rocks. Principal among them is the stratification of the deposits. This is well established in the Comstock region and it carries important deductions with it.

While no precise statement of the mode in which the rocks of the Comstock were extruded has been made, those who have written upon this subject seem to have regarded the history of the region as the following. Triassic strata covered the country, and through them burst in Jurassic time a vast mass of diorite which distributed itself in a cone or dome, of which the centre is now occupied by Mount Davidson. Upon that was poured the propylite and the other rocks in succession, and these eruptions were irregular in shape and enormous in quantity.

The idea which it is proposed to consider first is the dome structure of Davidson. Such peaks have been attributed to the pushing up of viscid lava through a central vent around which it distributed itself without flowing to any great distance, and this seems to have been the impression in regard to this mountain. But this view is opposed not only by the mode of occurrence of the diorite, which has been shown to lie in a long ridge, and even series of folds, and not in an isolated peak, but also by the very character of the rock. Diorite is one of the fine grained, thin running, lavas, and the Comstock does not contain any material of which unusual viscidity can safely be predicated on local grounds, unless it is the trachyte and perhaps the breccias.

In the protrusion of this mass the ancient fragmentary rocks are supposed to have been broken and thrown into positions of high inclination, and finally nearly removed by erosion. But the dome theory receives little support from the condition of the metamorphic strata. They do not have the wide distribution that is to be expected of an original surface which has formed the scene of extensive eruptive outbursts. They are never covered by the diorite but always lie upon it. They do not increase in depth as they should where protected by the propylite from erosion, but, on the contrary, give out entirely within five hundred feet of the surface. Though tilted they are not otherwise distorted, but seem to be quite regular in strike and not very much diversified in dip.

On the other hand, the amount of tilting they have undergone is rather an argument against the dome theory, for the usual testimony is that the ejection of trachytic domes does not disturb the strata much. Probably on this account it has been thought necessary to ascribe their elevation to a period of general folding and mountain making preceding or accompanying the eruptions, and in this way two things have been joined which are not compatible. The rising of longitudinal folds may prepare the way for fissures, but hardly for isolated volcanic vents.

All these considerations make it evident that a new explanation of the facts is needed, and they all sustain the probability that those rocks of the Comstock which are unmistakably igneous in their origin have issued from fissures successively opened, and have spread over the country in a series of superposed eruptive strata. In this view the fragmentary rocks must be later instead of earlier than the diorite, and the propylite later than either. Elevatory movements have followed the propylite instead of preceding it, though they may have *begun* before this material appeared.

As to the diorite peak of Davidson, its present elevation above the propylite is due to the fact that it occupies a point where three distinct forces combined their action, and there is no other point, in the immediate Comstock region, at which this combination did take place. The north and south elevation and the subordinate east and west folding combined to produce one highest point in the uplift, which point was subsequently denuded of its propylite by erosion, leaving the diorite projecting through the surrounding rock.

The propylite is shown to have the same stratified structure as the diorite, and the great number of andesite dykes indicate precisely the same state of things in the vast accumulations of that rock, provided we allow a separate eruption to each dyke, which is probable from the perfect individuality that exists among these dykes, no connecting fissures of even the smallest dimensions being discernible. This evidence is supported by the near proximity of many of the dykes. They form groups, the members of one group being often separated by sheets of propylite only a few feet—two to ten or twenty—thick. The existence of these thin partings of the original rock is proved by a dozen sections in some mines, all of which exhibit a thick dyke divided in two or several parallel portions by a sheet of propylite which the attainable sections show to be at least five hundred feet square and nowhere fifteen feet thick. It would be hardly possible for such a mass to maintain its integrity inclined at an angle of thirty or forty degrees, while a much thicker current of fluid material was pouring on each side of it. Its weakness establishes the individuality of the two dykes which inclose it. From this mode of occurrence it follows that the andesite overflow was also stratified.

With such a history it can hardly be said that the eruptive rocks of the Comstock represent the effects of violent convulsive movements. The accumulation of material is vast, but it is made up of individual members which, though large, are not of extraordinary dimensions. Their most noticeable feature is their extreme length and breadth combined with comparative thinness. They indicate widely extended operations occurring at intervals, with great regularity and perhaps with comparative quietude. The time involved was undoubtedly very long.

If this is also the history of the eruptive rocks which cover hundreds of thousands of square miles of our country, the notions of violent catastrophic movements as a *necessary* accompaniment of eruption must be abandoned. These rocks may have been laid down almost as quietly as their sedimentary rivals. The whole appearance of the Comstock indicates grand and gentle, rather than convulsive, action. That the successive layers of rock were not poured wildly and incessantly upon each other is proved by the periods of rest which are indicated.

Character of the Siliceous Epoch.—From the Rocky Mountains to the Pacific, or over an area several hundred miles wide, there is found a great variety of mineral deposits yielding gold, silver, lead, copper, antimony, mercury, and other metals. The country rocks containing them belong to various geological periods and are composed of almost every variety known to the lithologist. Limestones, sandstones, and clay, granites and porphyries are all represented in various modifications. But with all these differences there is one uniform characteristic. The country rock may be any thing, and the mineral may contain any metal combined with any substance that the laws of chemistry allow, but the gangue rock of the mines, through the whole of the immense region indicated, is preponderatingly *quartzose.* Some ores, of course, are basic, and others are called basic, but their basicity is mainly due to the presence of iron. Alumina and lime are usually both present, but if the iron were to be removed from the ores obtained in the West, it is probable that in most cases the metallurgist would have an extremely siliceous ore to treat. This is true, not only of such almost exclusively siliceous ores as those of the Comstock and the gold veins of California, but also of the "base metal" ores of Utah, Nevada, and California, as a few analyses quoted from various sources will show.

	Winnemucca Mine, Utah.	Emma Mine, Utah.	Ontario Mine, Utah.	Australian Sulphate Ore, quoted by Percy.
Silica	35·00	40·90	55·21	10·56
Alumina, lime, and magnesia	10·40	1·32	14·14	4·05
Ferric oxide	6·90	4·60	2·77	18·93
Plumbic oxide, etc.	47·70	35·64	27·21	42·34
Other metallic oxides and sulphides	.....	17·54	.....	0·74
Water	.....	.....	.....	3·48
Carbonic and sulphuric acid	.....	.....	.....	20·66

The ores of this region are known to metallurgists as neutral, basic, and acid, but in that designation the oxide of iron occupies a controlling position. As above said, very few if any of the Western ores, entirely free from country rock, would be basic if the metallic bases were removed. It is also to be noted that the proportion of silica, lime, and alumina does not seem to have the slightest relation to the surrounding rock. The ore of the celebrated Emma mine in Utah contained forty per cent of silica, though it lay in a dolomitic limestone. That of the Miller mine lying four or five miles distant, and in sandstone, had so little silica in proportion to its iron oxide as to be insufficiently acid for metallurgical treatment, and this comparison of two deposits lying near each other is apparently valid for many other mines more widely separated.

Some ores have the reputation of being basic which have no gangue at all in the true sense of the word. They are depositions in minute crevices and over the interior surfaces of any rock, usually limestone. Of this class are some chloride of silver deposits. The limestone is necessarily mined with the silver ore, but it had no part whatever in its origin.

Excluding all such deposits, and disregarding the metallic contents of the ore, it becomes true that the *earthy* constituents of the Western ores are overwhelmingly siliceous in much the larger number of mines, wherever situated.

A similar state of things appears to be true also for the world at large. In the metallurgy of most ores that require smelting it is found advisable to make such additions to the ore as will, in combination with the gangue, produce a slag having a composition lying between a proto and a bi-silicate and to do this it is almost invariably necessary to add a base. Iron oxide and lime are the standard fluxes in the treatment of ores containing silver, lead, copper, and iron. In those great metallurgical establishments of England to which ores of copper, lead, silver, and gold are carried from North and South America, Australia, Africa, and all parts of Europe, the proportion which contain an excess of earthy base is very small. For the most part they contain a large proportion and frequently an excess of iron sulphide, and by roasting this to oxide the smelter often avoids the introduction of foreign fluxes, but this constituent is excluded from present consideration, which is confined to the earthy components of ores. Leaving out all metals and also all admixture of country rock, it is probable that the filling of the world's metallic veins, like those of America, is mainly siliceous. This fact is remarked upon by Whitney, who says that quartz is the most common gangue of veins and " may be said to be almost never absent from any vein."

It is worthy of notice that when basic gangue does occur it is usually very strongly basic. There seem to be very few deposits in which acid and base are nearly evenly balanced among the earthy constituents. Freiberg offers one of the best examples of the individual occurrence of the two classes of ore. The distinctively quartzose lodes of that district number four hundred and fifty, and in them the earthy bases " occur only to a very subordinate degree," says Von Cotta. Another series containing three hundred and forty veins have a gangue which is basic from the presence of carbonates of iron and manganese, but its earthy component is mostly quartz. The remaining lodes of the district, one hundred and thirty in number, are basic, the filling being baric sulphate, or heavy spar. Thus Freiberg has seven hundred and ninety veins with quartzose gangue, containing only a mere trace of earthy bases ; and one hundred and thirty veins with basic gangue, containing little silica.

This universal predominance of silica in connection with the deposition of metals is a phenomenon of great significance for which no explanation has been offered, but one which geological science will some day be called upon to account for.

The tendency of recent discussion has been to refer vein-filling to metamorphic action. The water of the ocean is known to contain small quantities of the metals, and these would necessarily become incorporated in any sedimentary deposits made in it, not only in the water which such porous masses hold in considerable quantity, but also in various solid compounds precipitated through the agency of chemical reactions. Starting with the assumption that the metals now concentrated in veins were originally dissolved in the sea-water, it is plain that the solution must have been much stronger than the water of existing oceans, and the concentration in the rocks proportionately more important. In fact, examination of the earlier sedimentary rocks has demonstrated the presence of even the rare metals in them. They are repositories of gold, silver, copper, and other elements, which exist in small quantity it is true, but perhaps more widely diffused than in later deposits. When the temperature of these rocks is raised by a covering of subsequent depositions, the water retained in them may not only be heated sufficiently to act powerfully upon the buried strata, but may be set in motion toward the upper layers, and carry with it whatever is soluble. In this way solutions may be transported which are able to effect great changes in overlying rocks, and also fill up crevices in them, and these crevices would then contain a concentration of the metals and other soluble constituents of the underlying strata.

It is evident that the whole theory rests upon the relative solubility of the elements in their numerous combinations and under conditions of pressure, temperature, and gaseous solution, which are still quite obscure. What remains in the veins is that which was soluble below and comparatively insoluble at the surface; and before the theory can be considered fully established, it must be shown that the known filling of the veins answers this requirement. Of course the striking predominance of quartz as the gangue of metals is a fact of the greatest importance, and no theory of deposition can be considered established until it accounts in some way for the selection of this substance in preference to lime, magnesia, and others which are very abundant in all considerable formations, and much more soluble under those conditions which we have knowledge of than quartz. Silica is not one of the most soluble, but one of the least soluble substances, and judging from laboratory experiments the chemist would probably declare without hesitation that metalliferous veins produced by metamorphism are most likely to have lime, magnesia, and iron oxides for their gangues. Judging from the acknowledged results of metamorphism, we should reach a similar conclusion, for probably no other single result of this action equals in extent the introduction of magnesia into the lime rocks. But this element is not known to form an important part of any class of veins, though frequently present in small quantity. Even if the lime rocks are considered to act as filters in which magnesia is exchanged for lime, the case is not improved for the metamorphic theory, for lime also plays but a subordinate part as a gangue of the metals.

Although the theory of metamorphic origin of vein-stones has obtained wide acceptance, no explanation has yet been offered of the circumstances under which the metalliferous waters become charged with one of the least soluble substances, while other elements of great abundance in sedimentary rocks, and of much greater solubility, are rejected; nor how solutions of carbonic anhydride fail to take up elements which are known to have their solubility greatly increased by this agent, and yet dissolve energetically silica, which is not supposed to have its solubility so much increased. It is not intended to present in this place a rival theory, but merely to point out some deductions that may be made from the overwhelming predominance of silica as the gangue of ores.

The first deduction to be made from the universal occurrence of silica in metallic ores tends to increase the number of "true" veins. A large proportion of the ores are conceded to have a deep origin, and if so many are eruptive, why not all that are uniformly accompanied by silica, and occur in deposits that do not positively forbid such an origin? Second, other facts show that the ejection of siliceous waters may have taken place over great areas and not been restricted in any way to the individual fissures.

Under the given circumstances it is suggestive to find that there was in the Comstock district a well defined period of silica impregnation accompanied by base metals, following one of the great dynamic movements of the region, and that this siliceous epoch was interrupted by another exhibition of intense eruptive action that brought with it the addition of argentiferous and auriferous constituents to the waters which previously bore the silica, iron, lead, copper, and other metals.

The facts accumulated are not yet sufficient to support unqualifiedly a theory of a general flood of siliceous waters over the whole Western mining field, or more probably of several such floods, but they are enough to bring such a suggestion into view. The evidences of siliceous waters are by no means confined to the mineral lodes, nor to narrow lines such as veins and lodes occupy. The wide occurrence of silicified wood lying in extraordinary profusion in gravels and clays throughout the auriferous soil of California, and in less though still very large quantities in all the other States and Territories of that quarter, indicate a diffusion of siliceous waters in immense quantity and for a very long time as strongly as does the acid character of the gangue mingled with ores in the veins.

Were it not for this silicified wood a less startling hypothesis would be sufficient, and the origin of quartz in lodes connected with eruptive rocks might be simply ascribed to the local solfataric agencies which have so often closed eruptive activity. But the wide distribution of the altered wood forbids such individualization of the phenomena and points to more general action.

That such a wide-spread permeation of the soil by silica-bearing waters has taken place has long been recognized, but the flood has been attributed to atmospheric sources, and the rainfall has been looked to as the sole and sufficient agent for the silicification which has taken place. Such an explanation is at least assailable on its merits, and especially does it become doubtful when the petrefaction of wood is confronted with the other much more significant and general fact of the almost uniform siliceous filling of veins which are due to solfataric action, over this immense area.

It is the concurrent testimony of all observers on the Comstock that the lode has been filled from below and this must be the history of at least a large number of the veins in the West. With such a wide distribution of ore channels filled from below with silica, it is not presumptuous to predicate a similar origin for all or most of the vein stones that are chiefly siliceous. To bring in so vast a quantity of silica in solution, there would be required a flood of siliceous waters such as would form a geological epoch as well marked in its results, and as long continued in action as those which produced thick depositions of sediment. In a country which has been the seat of such tremendous eruptive action there is nothing startling in the conception of even such immense floods of mineral-bearing waters, as one of the solfataric phenomena, not less extensive and important than the great outbursts of igneous eruption. It has been said that all waters are meteoric, and though the contrary view has been maintained by some authorities, that may be granted without removing the possibility and even probability of the accumulation at great depth within the earth's crust of water under such conditions as to be released by a profound dynamic movement, just as liquefied rock is sent to the surface. In fact, the two modes of eruption form the two extremes of aqueo-igneous fusion, one having the least and the other the most water possible. In this way we may combine the atmospheric origin of the waters with their evident eruptive mode of penetration to the lodes.

As to the age at which the floods appeared and the filling of the veins took place, there is no other testimony than that furnished by the Comstock. There two well marked periods are discernible, the andesitic and trachytic, and both occurred at a date sufficiently recent to satisfy the conditions of all the known veins or lodes in other localities.

The Comstock also supplies the principal known exceptions to the siliceous character of this aqueous eruption. In the Justice is a vast accumulation of ore the gangue of which is calcite instead of quartz, the latter being deposited in a thin layer directly upon the country rock, with the lime carbonate upon it. The Lady Bryan ore also contains twenty or thirty per cent of calcite, but in the Justice this material must form ninety-five per cent of the gangue.

Upon the relative occurrence of this basic ore and that of quartz all that can be said of it is that the lime gangue is formed exclusively in mines that are half a mile or more east of the Comstock, and, therefore, according to other indications, they may be of later date. Opposed to this is the fact that the latest depositions—those still in progress, at Steamboat Springs—are exclusively siliceous.

Colorado also contains veins with true basic filling, the gangue being barite, fluorite, and calcite, and more careful study of this interesting field would probably increase the number of known deposits of this class. An analysis of the ore smelted at Dudley, Colorado, is given by E.D.Peters, as follows:

Baric sulphate, 55.
Calcic carbonate, 15.
Silica, 20.
Galenite, 5.
Sphalerite, 5.

CHAPTER XI.

THE JUSTICE LODE.

THE southern portion of the Comstock region is characterized by the presence of the most recent eruptive rocks, quartz porphyrite and basalt, and by the extensive exposures of metamorphic strata. Many claims have been staked out and mining has been prosecuted more vigorously on one line than in any other of the "outside" mines. Indeed, the Justice, which reported in 1877 a bullion yield of $2,339,057, has been so productive as to rise out of the despised class of "outsides" and take its place with the great mines of the Comstock. In the same quarter are the New York, Lady Washington, Alta, Justice, and Silver Hill, and as the lode which they work upon has a northwest strike, and its line if continued would intersect that of the principal lode, the question has long been mooted whether this is not a branch of the Comstock "vein." It has been suggested that the great lode forks in the lower part of Gold Hill, sending one branch in a nearly direct line to American Flat, and another at an angle eastward toward Silver City. That supposition was made when little was known of the Justice, and is no longer tenable now that the ground has been more fully opened. Such a branching is not an impossibility even with a lode that is not a vein, since two lines of pressure might run together and produce a forked arrangement of deposits. But if this had taken place it would have left traces which could not have been overlooked in the ground so thoroughly explored by the Overman, Belcher, and Crown Point mines. It is said that a line of surface croppings, connecting the two lodes, is discernible; but in the absence of underground indications this must be doubtful.

Like the Comstock mines the Justice has an andesite dyke for its west wall, and no sign of the meeting of the dykes has been noticed, though such an intersection could not have escaped observation and also exploration, for the Justice has an ore-bearing dyke vein like its greater neighbor.

While the ground has not been worked sufficiently to give positive proof of the fact, it is probable that the Justice dyke is identical with one of the andesite dykes lying in the east country of the Comstock. If so, it must bend as it progresses through the southern part of its course, and the cause of this change in direction is visible on inspecting the Justice ground.

In every respect this mine is one of the most important to the scientific student of all the openings within the region. Its upper levels still remain open for inspection, so that the history of *one* mine can be read from the surface down to more than a thousand feet in depth. Its ore is in a lime rock, calcite. It lies on the front of the greatest development of metamorphic rocks in the region, and finally, it presents in the most striking manner that crossing of the strata by the quartz bodies which has already been referred to as a feature that has not yet been recognized on the Comstock, though it probably exists there.

In describing the distribution of the rocks in this region, it was said that a broad, blunt wedge of metamorphic strata occupies the southern portion of the field, its base resting on the south and its apex directed toward the north. These rocks are partially overflowed by quartz propylite and basalt, and in one place a small exposure of granite rises through them. The northeastern flank of this wedge has a direction almost due northwest-southeast, and directly in front of it is the most considerable exposure of andesite in the whole field, the narrow intervening valley being formed in propylite.

Upon this northeastern front of the metamorphic strata rests the Justice lode. On the surface it appears to have quartz propylite for its west wall, as Von Richthofen said, but the explorations in depth have shown that the erupted rock is a mere cap, only covering the crest of the hill. At the depth of 92 feet from the mouth of the shaft is an old tunnel now used as a drain adit. It is run in from just above the level of the small stream in the gulch, and, after the dyke has been reached by a short crosscut westward, a narrow vein lying upon the dyke is followed for more than three hundred feet in a northwest course. This was the end of the old workings, the dyke vein being too thin for profitable extraction, though it supplied rich ore. When the Justice shaft was sunk somewhat east of this line, it was connected with the old tunnel by a crosscut for purposes of drainage.

Examination of this connecting crosscut from the shaft shows that the latter at this level lies in hornblendic porphyrite which forms a layer more than seventy-five feet thick. It is succeeded on the west by porphyrite one hundred and sixty feet thick, the western half of which is so much decomposed as to deserve the classification of ledge porphyrite. Then follows the dyke vein which, with its accompanying highly decomposed material, is about twenty-five feet thick.

The dyke vein has a slight western dip, and probably on this account the early miners were led to explore the ground west of it by a crosscut more than three hundred and fifty feet in length. It illustrates very forcibly the dogged persistence with which so much of the work in this country has been done, for in the whole of its course nothing was found but metamorphic rocks, penetrated midway in the crosscut by two dykes of hornblendic porphyrite. The andesite dyke is cut through close to the vein and is but a few feet thick. How much further this mass of altered strata runs in depth is not known, as there is but one other opportunity of observing it. That is on the 400 level, and there it is indistinct.

On the surface these alternations of rock are recognizable in spite of atmospheric decomposition. The dyke vein has been opened by stripping, disclosing the dyke on its western side. Without this aid the explorer would hardly be able to fix upon its location, so completely is the ground covered with shingle from the quartz porphyrite. The steepness of the hillside has compelled the cutting out of a roadway by blasting into the dyke at one place, and here the west inclination of the dyke vein is plainly visible. The dyke seems to lie upon it. It is partly owing to this west dip that the hornblendic porphyrite is found to be close to the dyke on the surface, but removed a hundred and fifty feet from it in the drain drift, ninety feet below.

The upturned edges of the porphyrite appear to abut against the metamorphic strata, which present their own edges to the erupted rock, all observers having agreed in the east dip of both the sedimentary and volcanic members of the series.

This abrupt abutment of two rocks so diverse in their origin and age is possibly only an appearance, for there is no evidence of faulting. The dyke may really occupy a cleavage plane in the sedimentary strata, and much of what is represented as propylite may be schists metamorphosed and subsequently acted on by the solfataric waters. Alteration alone has so changed these schists as to give them strong resemblance to basalt and andesite and it is entirely possible that near the surface they form some part of that indistinguishable mass which is necessarily called ledge porphyrite, and which is proved to consist of any thing the waters encountered in their path, every rock of the region except the metamorphic strata and the basalt having been recognized in it.

The line of contact would be the natural slope of a hill formed of granite or diorite capped by the fragmentary strata and fronting a valley. The latter was subsequently filled by propylite and the whole mass now occupies an inclined position produced by folding on the grand scale, so that the metamorphic strata have a dip which is equal to their dip before the entrance of the propylite, *plus* the tilting which they have since suffered in common with that rock. The propylite laid down in successive layers in the valley would show a series of strata abutting against the escarpment of the inclined fragmentary rocks, and this is the actual situation both in the Yellow Jacket and Justice examples.

In the Justice the great ore body which has supplied all the bullion from this mine rises to within one hundred and twenty feet of the surface, but it was first discovered on the 400 level, at an actual depth of 369 feet, where there is an extensive level. East of the dyke vein there is a mass of decomposed propylite, fifteen hundred feet long within Justice limits, and its southern end is occupied by an ore channel consisting of heavy masses of calcite and of propylite mixed with calcite. It is separated from the former by a clay seam known in the mine as the foot-wall. This ore channel is also lenticular in shape, but does not have the same strike or outline as the remainder of the decomposed porphyrite. The latter has a strike of about N. 60 W. magnetic, a length of eight or nine hundred feet, and a greatest width of about three hundred feet. The ore channel, in which is included all that part of the propylite which is most thickly impregnated with calcite, has a strike of about N. 30 W., a length of more than six hundred feet in Justice ground, and a width of two hundred and fifty feet.

This is not all ore, and is, in fact, only a more highly altered portion of the lode, in which is situated the true ore body, occupying the peculiar position described in the chapter on the position of the ore bodies. It lies across the ore channel, making nearly a right angle to that and a full right angle to the strike of the whole decomposed mass. It does not present its side to the dyke as the Comstock quartzes do, but its end. It is curved in form, the concavity facing southeastward. It is not parallel to any other feature of the formation, but in itself is divided into essentially parallel members by thin clay seams. This singular situation can be appreciated only by inspecting the map, Plate VI.

Not one of the peculiarities which this body of ore exhibits is maintained on lower levels. It is the most irregular mass ever opened in the Comstock region. For a hundred and fifty feet in depth it continues to lie transverse to the strike of the lode, but in size and shape, and in the direction of its convexity, it varies on every succeeding level. When a depth of two hundred and fifty feet below the 400 level is reached its course is no longer transverse but parallel to the lode and the entire ore channel shares in the change. This is shown in the 800 level, the true depth of which is 622 feet. Here the ore channel and the ledge propylite both retain their lenticular shape, but on the 1000 and 1150 levels (true depth 822 and 922 feet) the lenticular form is entirely lost and the formation consists of parallel layers which are clearly exhibited in the east crosscut, north drift, of the 1000 level.

It is noticeable that when this regular disposition of the eruptive strata is reached, they are found to have the same direction--about N. 60 W.—as the eastern face of the metamorphic strata, and this strike may have been determined by a fold due to dynamic action, and situated in the rock underlying the metamorphics. Probably the irregularity of the ore body in the upper levels is to be attributed to nearness to the surface and the presence of the metamorphic rocks. If so, they may have a depth of somewhat less than six hundred feet, since at that point their influence has ceased. The west dip of the dyke at the surface does not indicate a corresponding inclination in these rocks, for at the depth of 369 feet they are found to be about a hundred and twenty feet east of their position in the 92 feet adit. This gives an easting of 120 feet in 277 feet of depth, or an angle of sixty-four degrees eastward, which corresponds with an observation (65°) made in the crosscut through these rocks from the adit. The continuation of the lode below the probable depth to which the metamorphic rocks extend on the same strike which they have at the surface can be explained provisionally on the supposition that the granite on which they rest lies in a fold which has that direction.

We may therefore assemble the facts as follows: West of the Justice lode a granitic axis is exposed which is probably a continuation of the diorite mass of Mount Davidson. Upon it repose metamorphic strata reaching down to a depth of somewhat less than six hundred feet. The granite may be assumed to have a northeastward inclination and the altered strata a similar dip of sixty-five degrees, the surfaces of the two rocks forming a continuous slope, bold above and gentle below. Upon this double surface lies the propylite, and either at the contact, or in its neighborhood, is a dyke which follows the contact line. Upon this dyke is the usual narrow vein, which is mostly siliceous, contrary to the conditions of the ore body lying in the strata east of it. That is calciferous, and the rocks in which it rests, at the southern end of the Justice claim (and only there), show a diversity and an irregularity which is not now to be found elsewhere in the Comstock region. First, on the 400 level, there are thick masses of propylitic breccia, through which crosscuts three hundred feet long have been excavated. Below that, on the 800 level, an equally extensive and irregular deposition of quartz propylite is found, and this in its turn gives way on the 1000 and 1150 levels to narrow strata of gray and chocolate propylite, breccia, and quartz propylite in regular order.

In this explanation the position and course of the granite are entirely assumed, for there are no west crosscuts in the mine that could show its presence. The openings are carried down at an angle of about 40 degrees, which on the 800 level leaves a space of more than two hundred feet between the most westerly drift and the position that would be occupied by the metamorphic schists, or the granite, if they preserve their inclination of 65°. This space has never been explored, and for this reason it is impossible to say whether granite or altered strata form the western boundary of the propylite at this depth.

Still, the probability is that the Justice lode closely repeats the conditions observed on the Comstock. It is formed by a line of ore bodies disposed in the propylite near its contact with an underlying rock, and the decided change of inclination in passing from the 400 to the 800 level indicates a change in the direction of the subjacent contact line. The assumption here made is that this change also marks the termination of the metamorphic strata and the subjection of the lode to the influence of the granite.

Interesting as these conclusions are, they give way in importance to another fact which none of the mines on the Comstock have disclosed. In the latter, no unconformability has been shown between the dip of the quartz bodies and the dip of the propylitic layers; but this is not true of the Justice, where the line of folding produced by the subordinate pressure is not parallel to the erupted strata, but crosses them. The Justice bears every evidence of formation under the same circumstances that have been explained in discussing the Comstock. It is not a vein, there is no fracture, no fissure walls, and yet the line of its ore deposits is carried, not with, but *across* the layers of propylite! The most essential definition of a true fissure vein is satisfied when a deposit is shown to break indiscriminately across one stratum after another of non-homogeneous rock, and compared with this requirement all other signs of fissuring have justly been held to be of only secondary importance. But the Justice fulfils this condition, and yet it does so without ever having had a fissure!

Fortunately, the evidences of this singular fact are very plain, for no part of the Comstock offers such advantages for safe study as the Justice ground. The propylite is more diversified there and by more positive characters than in any other part of the region. It is made up of gray and dark brownish red porphyrite, quartz porphyrite, porphyritic breccia, and hornblendic porphyrite in alternate layers, and there is no mistaking these varieties. They cannot be confused, for their differences are so great as to offer sufficient basis for the distinction of true lithological species, acknowledged everywhere. It is here that the marked individuality of that species of propylite which has been denoted hornblendic porphyrite places it in an important *rôle*. All other kinds of propylite shown in the crosscuts of this mine are strikingly different in appearance and lithological composition from this. They are uniformly of gray and dark reddish brown or chocolate colors in which the quartz propylite also shares. All of these varieties contain hornblende, but it is usually small in quantity and almost invariably black, or brownish black in color. When a change is made from such layers to one which, like the hornblendic porphyrite, has a light-colored base, with greenish tinge, thickly studded with light green crystals of hornblende and milky crystals of feldspar, the aspect of the rocks shows a strong contrast. It is impossible to pass it unnoticed in a crosscut, and equally impossible to imagine that materials so different in character and so uniformly distributed should be only individualized portions of a great homogeneous mass.

This positive and prompt recognition of juxtaposed layers makes their stratification very clear, and it is to this part of the Comstock that the student should first direct his steps, for nowhere else is the interesting history of the lode rocks so plainly written.

The arrangement of the series is best shown on the 1000 level, where a long east crosscut, run from the north drift, gives an accurate section of its members. At this level the station is in a part of the porphyrite that is but little decomposed, but east of the hard rock there is about a hundred and fifty feet of the same material which is decomposed, and it has been colored on the map as ledge porphyrite. The north drift runs in this but does not cross it. About two hundred and fifty feet north from the shaft the west and east crosscuts, together five hundred feet long, disclose a series of six rocks. From the drift eastward the section is:

102 feet porphyrite No. 1, gray, reddish brown, sometimes porphyritic, much decomposed, and made up of layers.
75 feet hornblendic porphyrite No. 1.
18 feet quartz vein.
81 feet porphyrite No. 2, gray and reddish brown, fissile and wet in places. This is also disposed in strata.
120 feet porphyrite No. 2, hard, stratified, same colors as soft.
17 feet hornblendic porphyrite No. 2.
45 feet porphyrite No. 3, hard.
1 + feet hornblendic porphyrite No. 3.

The crosscut is so nearly at right angles to the formation that the section represents very nearly the true thickness of the different members. It ends in hornblendic porphyrite of unknown thickness. The undecomposed porphyrite in which the shaft station lies is a part of No. 1.

This series was maintained on the 1150 level, so far as the works disclosed it in October, 1877, but above the 1000 the conditions are entirely different.

Not only are the whole workings of the mine confined to the ground lying between the dyke and hornblendic porphyrite No. 1, so that the former is not seen, but other rocks enter the field in the southern part of the mine. These are quartz porphyrite, about three hundred feet thick on the 800 level, and porphyritic breccia of the same and even greater thickness on the 400 level. Thin layers of both of these rocks are found in the crosscuts from the shaft, but their great development is entirely confined to the southern end. On the maps they are both colored as propylite, of which they form varieties.

Both rocks have their especial importance. The porphyritic breccia carried the greatest development of ore, that on the 400 level, but this connection with the productiveness of the lode was probably entirely accidental and due to dynamic and not chemical causes. Its character as a fragmentary eruptive rock is valuable in confirming the fact of stratification, and this is one of the advantages offered also by the marked mineralogical characteristics of the quartz porphyrite and hornblendic porphyrite. None of the other varieties of propylite make the fact of stratification so impressively evident as these three rocks.

But the hornblendic porphyrite has also other claims to our attention. It is the relative position of this rock to the ore channel on successive levels which establishes the singular fact that the Justice lode crosses the propylite layers.

Plate VI. shows that from the surface to the 800 level the ore body and the so-called "quartz,'" which in this mine is calcite, always lie between the dyke and the first layer of hornblendic porphyrite. On the 400 the ore channel extends from the dyke to this layer. On the 800 the channel is far removed from the dyke, not less than five hundred feet of space intervening in the ground that has been explored; and it is impossible to say how much further west the dyke lies. At this depth the channel hugs the west side of the hornblendic porphyrite. Before the 1000 level is reached it has passed *through* this rock and at that depth is found on the *east* side of it. Reference to the vertical sections will show that this transfer in the position of these two members of the Justice lode takes place in consequence of a sharp vertical bend in the hornblendic porphyrite between the 800 and 1000 levels. The ore channel does not share this change of dip, but keeps on in its old inclination and therefore passes its neighbor in the vertical part of its course.

Plate VI.

Fig. 4 1000 LEVEL (1754)

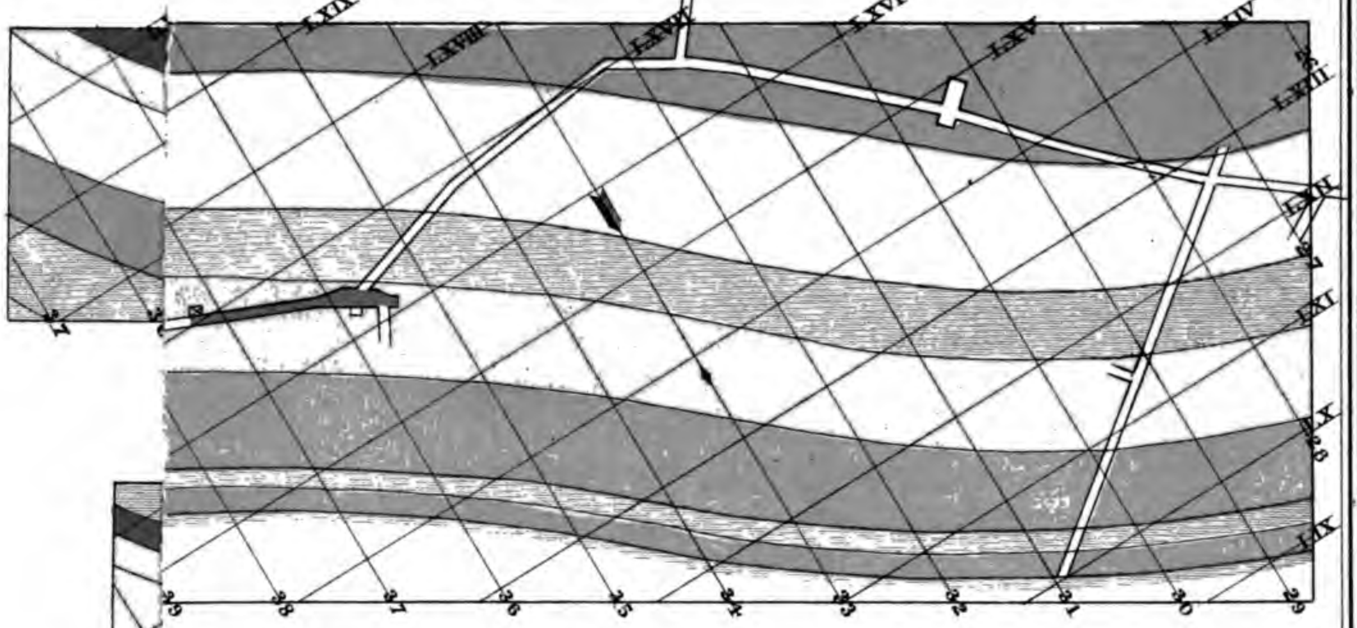
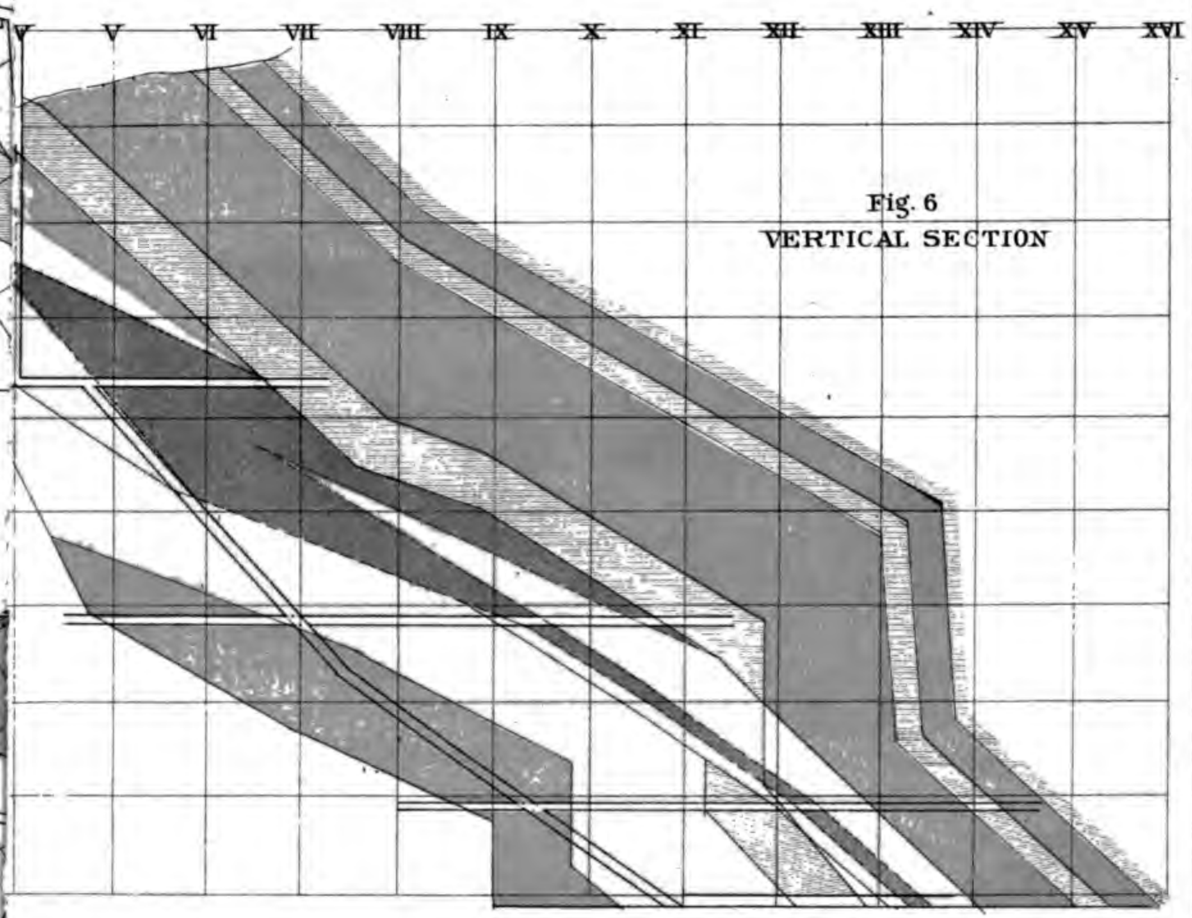
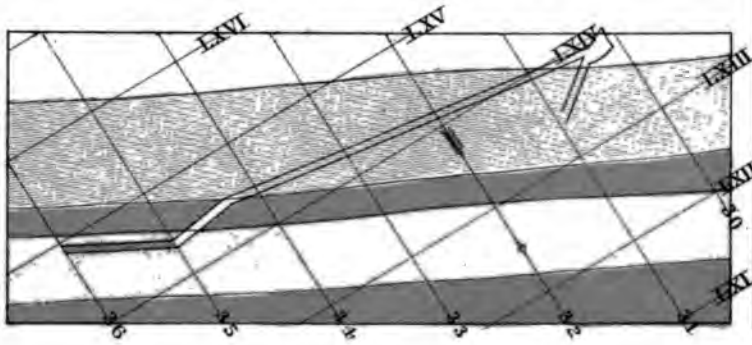


Fig. 6
VERTICAL SECTION



Porphyrite
Andesite
Calcite-Ore Channel
Stopes
Ledge Propylite
Metamorphics
Hornblende Porphyrite

Fig. 5 1150 LEVEL (1854)



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On the 1150 level we find these facts confirmed. While on the 1000 the ore channel lies immediately upon the hornblendic porphyrite, and the latter is partially involved in the solfataric decomposition, the ore is separated from this layer, on the 1150 level, by fifty feet of undecomposed porphyrite. This gives a dip of thirty-five degrees. The ore channel has an average dip from the ninety-two foot drain drift of about thirty degrees, and the propylite, including the vertical portion between the 800 and 1000 levels, has a dip of forty degrees.

The Justice lode, therefore, crosses the propylitic strata not because of a different strike, but in consequence of a different dip. Still this departure from the conditions that are usually understood when it is said that a vein crosses the formation does not lessen the completeness with which it satisfies this fundamental requirement of a "true fissure vein." The facts in the case are unmistakable. There is no confusion or dimness of the circumstances, the strong distinction between hornblendic porphyrite and other forms of propylite forbidding error.

In giving the section exhibited in the east crosscut, north drift, 1000 level, the different layers were shown to consist simply of alternations of porphyrite and hornblendic porphyrite, and each of these was numbered 1, 2, 3, from west to east. The ore channel lies in porphyrite No. 1, from the surface to the 800 level; in hornblendic porphyrite No, 1, from the 800 to the 1000 level; and in porphyrite No. 2, below the latter. It is making its way rapidly eastward, and unless some change in inclination throws the propylite into parallelism with its dip it must soon cross its present host and enter upon the much thinner strata of No. 3 of both rocks.

It is hard to say what has produced this unconformity in the angle of the ore channel and the propylite. The phemonenon *per se*, is not unknown in the Comstock mines, where the great bonanzas have been formed, as before explained, by the removal of several propylite layers which were crossed by the line of folding, and their partings opened for the admission of siliceous waters. But no instance has been discovered there which resembles the crossing of successive propylite strata by a narrow ore channel, as in the Justice, and from one fact it may be concluded that the phenomenon is not exhibited so positively there. That fact is the absence of a dyke in the Justice lower levels. Below the 400 level the dyke is not seen, the ore channel cuts loose from it and apparently has a much smaller dip. Opposite the metamorphic strata the mean of the west and east dips of the dyke down to the 400 level appears to be about seventy degrees, and since the ore channel has a dip of only forty degrees they separate by an increasing distance as they descend. These conditions are precisely the reverse of those found in the Comstock, where the ore channel sometimes has a steeper inclination than the dyke for a short distance, but never a less one, except as a very local phenomenon.

While the cause of this peculiarity must remain obscure in the absence of positive exploration westward from the ore channel, it is possible that the inclination of the latter is governed by the rock underlying the propylite. We may consider that the channel runs parallel to the underlying granite and is uninfluenced by its immediate surroundings, except near the surface where the metamorphic schists have displaced it. By this supposition the fragmentary strata occupy the crest of a granitic fold the slope of which decreases as it descends in the trough. There may in fact be another fold in the granite below the 1150 level, and if this is true the Justice is likely to encounter this granite west wall at some point in depth, though perhaps not for a considerable distance from the surface.

The crossing of the formations by the ore channel is only one of the two peculiarities which the Justice lode exhibits. The other is the relative position of the dyke and the layer which has been called hornblendic porphyrite No. 1. At the surface the two are almost in contact, only the dyke vein and a few feet of porphyrite intervening. On the 400 level they are three or four hundred feet apart and on the 800 level they are six hundred feet apart, besides an unknown quantity of unexplored ground. Porphyrite No. 1 rises to the surface it is true, but only as a wedge which shows no promise whatever of its enormous thickness six hundred feet lower down.

Such circumstances may be explained by the supposition that this mass of porphyrite lies in an old trough formed by a fold in the granite which carried metamorphic schists on its crest. The first flows of porphyrite would fill up the trough and show an irregular lower surface with a regular upper surface. This appears to be the case in the Justice, where the trough was filled by porphyrite No. 1, and hornblendic porphyrite No. 1 was the first layer deposited upon the levelled surface. A large part of this filling was accomplished by porphyritic breccia, thick sections of which are shown in the mine.

The wide separation of the hornblendic porphyrite No. 1 and the dyke on the 800 level is accompanied by the interposition of thick masses of quartz porphyrite, but higher up there is no apparent connection with the heavy outflow of this material which caps the Justice hill, except in a layer thirty-five feet thick on the 400. This may be a dyke, but it is also quite possible that there is no connection between these subterranean developments and the local surface depositions of this rock. Still its peculiar concentration in the southern part of the mine, just where the hornblendic porphyrite makes a great bend, hints at injection rather than an overflow, forming one of the series that built up the propylite. Questions like this cannot be decided until the mines bordering on the Justice are carefully examined.

Among the phenomena of the lode is the peculiar position of the dyke vein. On the 400 level it is seen to leave the dyke and turn toward the east. This portion of it has been explored for nearly four hundred feet by the main drift of the level, so that the phenomenon, which would otherwise be doubtful, is well exhibited. Whether it finally abuts against the hornblendic porphyrite No.1, or turns into parallelism with it, could not be decided, as the drift north from the station was closed. The probability is that it does abut, or run out against it, for otherwise the north drift would not have been stopped within a hundred and twenty feet of the station and fifteen hundred feet from the boundary of the mine. It is impossible to say what produced this divergence of the vein from its dyke, unless it was caused by the presence of the heavy masses of porphyritic breccia on this level, all of which lies south of this branch. Below, on the 800 level, there is neither dyke nor dyke vein to trace.

The ore of the Justice is not quartz but calcite, with but an insignificant amount of silica, and it is noteworthy to find these two components of the lode disposed in that banded arrangement which is another of the accepted proofs of a true fissure vein. The quartz is always on the propylite and the calcite on the quartz, but there is no comparison in respect to quantity. The quartz is always insignificant in thickness, never reaching a layer more than an inch or two wide so far as noticed, except in the dyke vein, while the calcite forms masses which are several yards in thickness. This calciferous deposition is also characteristic of the Lady Byran mine, which lies in the northern part of the region and a mile or more east of the Comstock. It is also a peculiarity of the propylite in this eastern portion of the district, where the rock is found to contain much lime carbonate. This indicates a cessation of the siliceous waters and their replacement by a lime solution, but there are no indications of the date at which the change took place. It is remarkable that the two fields of deposition should have been kept so distinct. The western side of the district has no calcite, and the eastern side is chiefly calciferous.

The conditions of the Justice may probably be summed up about as follows: One of the andesite dykes which lie east of the Comstock lode, in its course due southward arrives upon the region of metamorphic schists, and turning from its true course continues in a southeasterly direction along the face of its new wall-rock. These schists are, however, limited in depth, not sinking further than six hundred feet from the surface, and below this point the dyke pursues its way in its new direction, it may be upon the granite on which the altered strata rest. It is accompanied by a dyke vein through which the neighboring rocks have been supplied with solfataric waters, holding first silica and then lime carbonate in solution. In the propylite a line of small crevices is opened in the partings of the strata and calcite deposited in them, with a dip of 38° to 40°, or the same as the propylite. They form an ore channel, which is produced by a force that acts independently of the bedding of the propylite and is thereby carried across a sharp fold in the strata, producing a true cross lode. In this channel the ore when opposite the metamorphic schists stands in a mass at right angles to the dyke, but below those rocks it is always parallel with it. Accordingly, the ore body turns a complete right angle in descending four hundred and fifty-three feet, and without losing its continuity.

As to the force which has produced these singular results there is no doubt that it was the same that made the Comstock. There is no sign of a fissure, or of vein walls, in spite of the undoubted crossing of the strata by the ore channel. The causes which have produced such an anomaly on the Comstock as an ore body lying (in the upper levels) in an east and west direction are obscure, but they may consist either in the peculiar bedding of the breccia or in the relative position of the lode opposite the metamorphic strata and the mass of andesite, or of trachyte; and in the effect of the subordinate pressure under their influence.

Considered in relation to the general theory of veins, the Justice completes the criticism which the whole region offers upon the existing systematic definitions. It shows that a lode may satisfy every condition of a true fissure vein (except its walls) and yet not show a fissure. The Comstock lode consists of a series of deposits produced by substitution, and not violating in any way in the lower levels the position of the strata out of which they are formed; but in the Justice the line of force which the ore channel occupies disregards the stratification and steadily crosses it, not by its own deviation from a right line, but by changes of dip in the strata. It finishes in a peculiarly striking way the lessons of this remarkable district.

Its workings have so far been confined to the first thousand feet from the surface, and there is good reason for expecting that somewhere in depth it will lose these oddities of formation and resemble in every respect its greater neighbor.

CHAPTER XII.

HEAT PHENOMENA.

AMONG the causes which have produced the celebrity of the Comstock mines, the fact that they are the hottest excavations in the earth's crust stands out prominently. It may even be placed above their extraordinary production and great depth, for during a few years past the most remarkable stories have been published widely of their temperature and the conditions of work in them. Even reputable professional journals have willingly certified to the existence of a temperature of 160° Fahrenheit and of a rain of hot water in the drifts that would be unendurable but for the use of iron shields to divert the streams from the workman.

A faithful recorder would have a hopeless task in endeavoring to make the truth as thrilling as these fictions, but nevertheless the heat of the mines is not the least extraordinary of their phenomena. The geological value of these thorough explorations in a mass of eruptive rock and along the course of an independent eruptive dyke lying within them has been pointed out, and they are not less important to the study of terrestrial temperatures. In other regions high variations of temperature are mostly confined to artesian wells, where observations are made with difficulty, and the true conditions surrounding the heat phenomena are rarely known. In the Comstock mines the thermometric range is greater than anywhere else, even in the artesian wells, and the observer can place himself in the presence of the cause which produces the heat, occasionally witness its method, and always have about him the *maxima* and *minima* of its results.

Under these circumstances I make no apology for presenting the facts and my conclusions respecting the heat phenomena at length, and indeed I have only to regret that the former are so incomplete and unworthy of their important subject.

The muscular action of a workman and the combustion of his candle have been estimated by Despretz* to be sufficient to raise 1000 cubic feet of air per minute, one degree in temperature, and usually these are the principal sources of heat. On the other hand, most mines are wet, and the vaporization of moisture by the air current cools the mine, and more so in summer than in winter. This is true even of abandoned mines, where only the natural phenomena of the earth's crust are called in play. But when the excavations are actively occupied, the contrast to the exterior temperature is much heightened by the conditions of labor in them. These contrary causes sometimes neutralize each other, and sometimes one or the other is in the ascendancy according to the season. As a rule, mines are warmer in winter and cooler in summer than the atmosphere, and this was the state of things in the first thousand feet of depth in the Comstock mines. The temperatures given in Mr. King's work are all of them above the winter and all below the summer temperature of the atmosphere at that locality; with one exception. The Imperial shaft had then reached a depth of 1084 feet, or perhaps somewhat more, and the temperature in the bottom is recorded at 97° F. As that work progressed in depth, the heat rose so much that three men died in the shaft from its effects alone.

Although the first thousand feet of depth did not show more than occasional departures from the thermal condition of most mines, the second thousand feet have been the theatre of the most remarkable heat phenomena known. The heat is no longer the result of muscular effort and the combustion of candles. It proceeds from the rock, which maintains constantly a temperature very much higher than the average of the atmosphere in Nevada, and higher than its summer extreme.

The heat of these mines is a matter of more than usual interest, for they are the only hot ones now worked in the United States, and both in the present temperature encountered and in the increase which is to be expected as greater depths are reached, they appear to surpass any foreign mines of which we have a record.

Hot mines exist in other countries also. Some of the Mexican mines excavated in eruptive rocks similar to those of the Comstock region are known to be hot; but no precise data concerning their temperature are attainable, and the only comprehensive observations that have been made are those of Henwood in the mines of Cornwall. Some of his results are given in the following table:

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* Quoted in Useful Metals and their Alloys, p. 107.

MINE.	Depth in Feet.	TEMPERATURE.	
		Air.	Rock.
Tresavean	1,584	86°	83° to 85°
Consolidated mines	1,500	87°	86°
" "	1,722	94°	93°
" "	1,764	94° to 96°	92¼ to 93¼°

He found that differences of temperature existed not only in the different kinds of lodes, but also in the varieties of rock, and gave the following oft-quoted comparison of the number of feet vertical depth in which the temperature rises one degree Fahrenheit:

In granite	51·0 feet.
In slate	37·2 "
In cross veins	40·8 "
In lodes	40·2 "
In tin lodes	40·8 "
In tin and copper lodes	39·6 "
In copper lodes	38·4 "

It will be noticed that in the first of these tables, the air of the drifts is always hotter than the rock in which they are excavated. This state of things has never been observed on the Comstock since the mines penetrated the hot ground. There the temperature of the rock is so much above that of the air that the effect of human occupation is proportionately insignificant. In addition to this the employment of drilling-machines worked by compressed air, precisely at the points where the men work and candles are burned, introduces a source of refrigeration by the expansion of the compressed air, which is probably fully equal to the heat derived from artificial agencies, except in the large ore bodies where an army of men work together.

The temperatures above noted are not the highest that have been observed in Europe. Some mines were reported to the British Coal Committee as having temperatures of about 106° F., and the hot lode in Cornwall has water of 116° F. at a depth of 220 fathoms, or 1520 feet. In the latter case, the air showed a temperature of 100° to 113° F. The highest temperature on record from the

Cornish mines is that of water in the Huel Clifford, given by Mr. J. A. Phillips at 125° F.

In the Comstock the highest water temperature observed up to the end of 1877 was 154° F., and the great mass of rock in the 2000 foot levels appears to have a pretty uniform temperature of 130° Fahrenheit. This was the reading obtained on several occasions by Mr. Comstock, foreman of the Ophir mine, and about the same temperature was found by Mr. Perrin, foreman of the Chollar-Potosi, Mr. Cosgrove, foreman of the Yellow Jacket (139½° and 136° F. at a depth of 2200 feet), and by myself in the Crown Point and other mines.

These readings were obtained by placing a thermometer in a drill-hole immediately after the hole was finished, and leaving it there for periods varying from ten minutes to half an hour. Very little difference was discovered between holes which were drilled wet or dry, or if wet, between holes which were naturally wet, and those which were made so artificially. No doubt there must be some difference due to these varying conditions, but they are so slight as to be completely masked by the great and steady flow of heat from the rock during the exposure of the thermometer.

The holes in which the thermometers were placed were not sunk especially for this work of testing, but were the ordinary drill-holes made for the purpose of blasting the rock. They varied therefore from about ten inches to three feet in depth. No variations in the height of the thermometer were found to be caused by this difference of depth, and the circumstances of the case are such that none were to be expected.

It was shown in the first chapter that mining on the Comstock proceeds with extraordinary rapidity. The drifts are advanced steadily, at the rate of three, five, and sometimes even eight and ten feet a day, and therefore the ground in which the miners are working is always fresh ground. The low conductivity of minerals to heat forbids the supposition that a rock of 130° Fahrenheit temperature can lose heat sensibly to any depth in the course of twenty-four hours, especially in a face which is not exposed to a passing current of air, and is not even approached by a greater current than one thousand cubic feet per minute of air already heated above 100° F. The shallow holes which were made use of always lay in new ground, and exhibited results which may be accepted with as much confidence as if they were twenty feet or more deep.

Very often they were in ground which had been exposed only one or two hours, having been sunk immediately after a blast which threw off four or five feet of the rock. The surface which was thus thrown down had not been exposed more than twenty-four hours. The high temperature and small flow of air in the heading forbid the supposition that any sensible diminution of heat could have taken place at the bottom of the drill-hole under such circumstances.

The heat phenomena of these mines vary according as the observations are applied to the rock, the water, or the air. A number of observations upon all these at different levels are presented in the following table. They are arranged with reference to depth below the collars of the respective shafts and the depths below the constant datum " Point A" are also given.

TEMPERATURES OF ROCK, WATER, AND AIR.

Depth.	Depth below Point A.	Mine.	Locality.	Rock.	Water.	Air.	Remarks.
Surface.	213	Savage.	......	......	......	97, 98, 99	Upcast curr't, June 29,'77.
"	238	Con. Virginia.	......	......	......	88, 89½, 90	Upcast, June 30, 1877.
"	662	Overman.	......	......	......	92, 93	" " "
"	277	Julia.	......	......	......	68	Downcast, morning.
......	......	Hale & Norcross	Drain adit.	......	140	......	Water in measuring-box.
......	......	Chollar-Potosi.	Air-shaft.	......	......	82	......
400	797	Utah.	North drift.	......	60	......	Standing water.
700	1,362	Overman.	Crosscut outside of "vein."	98	......	......	Hole plugged, exposure of thermometer, 24 hours.
756	969	Savage.	......	......	126	104	Air in shaft, water in pump-tank.
900	1,562	Overman.	Crosscut outside of "vein.'	101	......	......	......
1,000	1,414	Belcher.	C'sscut to air-shaft.	......	......	82	Downcast.
1,050	1,263	Savage.	......	......	129	......	Water in pump-tank.
......	......	"	C'sscut to pump-t'k	......	......	123	Near tank. No current.
......	......	"	Station.	......	......	97	......
1,100	1,268	Chollar-Potosi.	East crosscut.	128	......	112	......
......	......	"	......	......	......	111	Air in air-pipe.
......	......	"	Station.	......	......	94	......
1,100	1,514	Belcher.	Drift.	......	......	92	......
......	......	"	Stopes.	......	......	92	Near foot wall..........
......	......	"	"	......	......	94	Higher.
......	......	"	"	......	......	100	Hole in roof.
1,100	1,762	Overman.	Crosscut.	95	......	......	50 feet east of "vein."
......	......	"	"	97	......	......	In "vein."
1,150	1,547	Utah.	North Drift.	......	......	74	......
......	......	"	South-east drift.	......	......	82	......
......	......	"	Sierra N. connection	......	......	74	......
1,200	1,862	Overman.	Crosscut.	99	......	......	60 feet west of "vein."
......	......	"	"	107	......	......	In "vein."
1,250	1,612	Sierra Nevada.	Station.	......	......	86	Near shaft.
......	......	"	"	......	......	97	At donkey engine.

TEMPERATURES OF ROCK, WATER, AND AIR.—Continued.

Depth.	Depth below Point A.	Mine.	Locality.	Rock.	Water.	Air.	Remarks.
1,300	1,563	Ophir.	North drift.	......	......	96	Air-pipe.
......	......	"	......	......	......	98	Drift.
......	......	"	......	......	......	100	Crosscut from drift.
1,300	1,513	Savage.	Air-way from Norcross.	......	......	91, 92	580 ft. from H. and N. line, very cool and refreshing.
1,300	1,962	Overman.	Crosscut.	98	......	......	65 feet west of "vein."
......	......	"	"	104	......	......	In "vein."
1,400	2,062	Overman.	Crosscut.	111	......	......	150 feet west of "vein."
......	......	"	"	115	......	......	In "vein."
1,465	1,728	Ophir.	South drift.	......	......	68	Air-way.
......	......	"	North drift.	......	......	86, 94	June 26, 1877.
......	......	"	"	......	......	108,109,112	Aug. 27, 1877, in headers.
......	......	"	"	......	......	109	In air-pipe.
......	......	"	" crosscuts.	......	......	102, 112	In headers, June 26, 1877.
1,500	1,738	California.	North drift.	......	......	94	......
......	......	......	Shaft.	......	......	92	June 30, 1877.
......	......	......	All stopes,	......	......	92	Air good
......	......	......	with one exception	......	......	93	when in motion.
1,550	1,788	Con. Virginia.	Station.	......	......	96	......
......	......	......	Gould & Curry drift	......	......	90, 91	Air-way.
1,600	2,033	Yellow Jacket.	New shaft.	105	......	......	Wet hole, 20 inches deep.
1,600	1,813	Savage.	North drift.	......	......	92	Air-way from Gould & Curry.
1,600	1,863	Ophir.	North drift.	......	......	114	Header.
......	......	"	"	......	......	114	Air-pipe, 800 feet long.
1,650	1,888	California.	North drift.	......	......	84	Air-way near Ophir line.
......	......	"	Stopes.	......	......	93	......
......	......	"	Winze, 40 ft. down.	......	104	......	......
......	......	"	East drift,	112	......	......	Old drill hole at header,
......	......	"	"	......	......	102	......
......	......	"	Stopes, 6th floor above level.	......	......	88	......
1,700	1,963	Ophir.	Winze down at Cal. line.	......	......	100	......
......	......	Ophir.	Do. crosscut at bottom.	......	......	110	In dyke.
......	......	Ophir.	" " "	......	140	......	Deep drill hole, partly in dyke.
......	......	Ophir.	E. crosscut, N. drift.	......	......	120	Runs to dyke.
1,700	2,062	Sierra Nevada.	South drift.	......	......	80	Air-pipe.
1,700	1,963	Ophir.	Winze.	......	120	......	......
1,732	2,165	Yellow Jacket.	Air-way between S. and N. winzes.	94	......	......	18-inch hole in surface, about 2 years old.
1,800	2,077	Julia.	Station.	......	......	84	Downcast, Aug. 8, 1877.
......	......	......	East crosscut.	......	......	108	......
......	......	......	Winze.	......	130	......	Winze full.
......	......	......	Station.	......	156	......	Water from dyke.
1,800	2,214	Belcher.	South incline.	......	120	......	Bottom, standing water.
......	......	......	......	......	135	......	Stream direct from rock.
1,900	2,163	Savage.	South drift.	......	......	106	......
......	......	"	North drift.	130	......	102	Header.
......	......	"	South drift.	......	......	96, 96½	Air-way from Norcross.
......	......	"	Main incline.	......	154	104	Water of flood which drowned the mine for three years.

TEMPERATURES OF ROCK, WATER, AND AIR.—CONTINUED.

Depth.	Depth below Point A.	Mine.	Locality.	Rock.	Water.	Air.	Remarks.
....	....	Savage.	Main incline.	......	......	92	In air-box from 1813.
....	....	"	1813 level.	......	......	92	At fan, where air for incline is supplied.
2,000	2,469	Crown Point.	South drift.	......	......	108	In air-pipe.
....	....	"	" station.	......	......	88	Downcast.
....	....	"	"	......	......	112	In drift.
....	....	"	East crosscut.	......	......	134	Outside bulkhead.
....	....	"	"	......	127	150	Inside bulkhead.
2,001	2,232	Imperial.	North drift.	......	123	....	Hot steam confined behind lagging.
2,000	2,433	Yellow Jacket.	Air-way between S. and N. winzes.	104	......	....	18-inch hole in surface about one year old.
2,135	2,366	Imperial......	North drift.	......	......	106	....
2,200	2,633	Yellow Jacket.	South drift.	139½	......	110½	Dry hole, 12 inches deep.
....	....	"	East crosscut.	136	......	109½	Wet hole, 12 inches deep.
....	....	"	West crosscut.	138	......	....	Dry hole, 12 inches deep.
....	....	"	South drift.	120	......	....	Thermometer laid on surface of rock.
2,400	2,631	Imperial.	....	141	......	....	....
2,480	2,833	Yellow Jacket.	New shaft, N. drift, 60 ft. S. of N. line.	152	......	....	East side, diamond drill wet hole, exposure, 18*h*.
....	....	....	Ditto.	152	......	....	West side, diamond drill wet hole, exposure, 18*h*.
....	....	....	Do. 160 ft. south of north line.	152	......	....	West side, diamond drill dry hole, exposure, 18*h*.
....	....	....	East crosscut from north winze.	154	......	....	Discharg'g a small stream of water.
2,670	3,103	Yellow Jacket.	New shaft.	155	......	....	In shaft, self-registering thermometer. Dry hole.

Rock Temperatures. These are higher in the Comstock than in any other locality which has been under observation, and they present remarkable peculiarities in many respects. The rock is not uniformly heated throughout, but contains restricted areas where the heat rises very much above or sink below the temperature of the surrounding mass.

It is impossible to reason with confidence upon phenomena which are so entirely novel and have not been examined sufficiently for complete exhibition. Variations occur, and corresponding levels in different mines do not show the same temperature; but in considering the observations made, I felt confident that a more thorough series would exhibit a groundwork of practically uniform heat phenomena, upon which local fluctuations would occur through the operation of special causes. In the study of such subjects it is always necessary to remember that the mining works do not follow the lines of heat manifestation, but intersect them in every possible manner, so that the thermometer hung in a level in one mine may be recording phenomena which are not encountered in the neighboring mine on that level, but are found and recorded several hundred feet above or below. On this account, in reporting in 1878 upon these remarkable temperatures, I ventured to distinguish strongly between the general and the local phenomena. The latter consist entirely in elevation or depression of the temperature.

The first observation of this local elevation of temperature was made in the Belcher south incline, a short distance above the 1900 station, where there is a hot spot quite narrow, but very evident to the senses. The east crosscut on the Crown Point 2000 level could not be visited, having been temporarily closed until an air connection could be made in the main drift, but by thrusting a thermometer through the bulkhead I obtained a reading of 150° F. for the air, and the air which filtered through the cracks in the bulkhead was sufficient to raise that part of the drift from its ordinary temperature of 112° to 134° F. Both of these readings were obtained in a cul-de-sac where there was no ventilation, but they indicate the existence in the crosscut of a point of unusually high temperature.

The Imperial mine is noted for its heat, and four men have died in it from this cause alone. In this mine the black dyke splits, sending a shoot off to the northeast, and a drift has been run on the two thousand foot level, along the eastern side of this branch dyke.

This proved to be a very hot spot indeed. Rock, air, and water were all so much above the usual limits of temperature even in these hot mines, that the work of cutting the drift must have been extremely severe. It might not have been accomplished but for the expedient of boarding or "lagging" up the sides of the drift with a double thickness of plank, breaking joints. This confined the water, which poured down the walls, to a tight chamber, and left the main part of the drift for the men to work in with comparative comfort. The lagging remains, and has been carried around into the main drift, which is still in active use. Its joints are calked with tow, and, one of these being stripped for me, the steam from the water immediately poured out and proved to be scalding-hot when tested by the finger. I did not, however, succeed in getting a fair reading of the thermometer, because the crack was too small to admit more than the end of the bulb. The thermometer must have been cooled by the evaporation of condensed moisture from its bulb ; but, even under these adverse circumstances, the temperature of the steam was taken at 123°. The incline below the 2001 level of this mine is also very hot, and, without testing it, I estimated its air temperature at 130° F.

On the 1900 level of the Gould & Curry a drift was begun in 1877, which proved to be extremely hot, and three men lost their lives in a winze leading up from it. According to the testimony their death was due to heat alone, and not to bad air. Other hot spots were frequently noticed in the mines.

Unfortunately, I have no observations of the rock temperature in these hot places, unless the 136° and 139½° F. reported by Mr. Cosgrove on the 2200 level of the Jacket is one. At the time the existence of these hot spots had been established my other duties were too pressing to permit me to give them the attention they deserve. So far as known, all the readings given in the table were taken in the general mass of the lode and country rock, and away from these localities. This is probably not true of the *air* temperatures, some of which are evidently affected by the existence of hot spots in their immediate neighborhood. These observations will be referred to again.

Even more singular and, for the locality, abnormal is the existence of points which are as much below the temperature of the general mass as the hot spots are above it. These cold spots are not numerous, but there is a very noticeable one in the Justice 800 level, at a depth of six hundred and twenty-two feet below the surface. None of the mines in this region are noticeably hotter than mines usually are until the depth of about 1000 feet is passed, and the Justice is no exception to the rule. It presents a striking contrast to the deeper workings on the Comstock, for though its temperature is elevated, the increase appears to be due to the heat from the candles and men. It offered a favorable means of comparison, but one which had to be neglected for the reason given above.

Cold spots are found in other mines also, though none was noticed that was so well marked as that in the Justice. They are usually or always wet, and the water that drips down is noticeably cold to the touch and cools the air of the drift. It is to this phenomenon that their discovery was due. The foreman of the Justice mine called my attention to the striking change of temperature experienced in passing through a few feet of the 800 main drift. The cooling effect continued for a long distance beyond the point where it was first noticed. Lest the refrigerative effect should be attributed to the presence of water by those who are not familiar with the Comstock mines, it may be well to mention that water drips from the walls in countless places, and it is usually warm and frequently very hot.

These cold spots complete a well-linked chain of heat phenomena, extending from rocks that are sensibly cold to the touch, and may not have a temperature above 60° Fahrenheit, through rocks that have the average atmospheric temperature, and those which are as hot as surface rocks ever become in Nevada, to those which have a temperature of 157° Fahrenheit. There is no reason to doubt that the gradation is regular, and the transition from the lower to the higher temperature is probably made through a much larger series of intermediate steps than the accidental thermometer readings taken show.

Finally, in the chain of testimony relating to this phenomenon is to be noted the condition of the rock. Wet places have been spoken of, and these indicate the position of water-ways, many of which appear to reach the surface, but they are of limited breadth. This water is usually hot, but sometimes cool to the touch, or tepid.

But wetness is not the most common condition of the rock. In spite of the vast reservoirs of water from which the mines have so often been flooded, the great mass of rock is perfectly dry, though very hot. That is the case in all the mines. Wet rock is the exception, and dry rock the rule, through the whole lode. In the drifts cut through this hot, dry rock, the walls of the freshly exposed surfaces are painful to the hand, and the air is often filled with dust. The rock is both hard and tough, but, in spite of its strength, it gives an impression of fine porosity to the touch, due probably to its trachytic character. It often has the odor of clay, but not always. It may be slightly adherent, or the impression of dryness upon the tongue may be due to its heat.

The hot areas appear to be quite narrow, and in descending a winze or passing through a drift they will be quickly passed in most cases. They are noticeably frequent in the neighborhood of the black dyke, and examples of this situation are found in the hot drift of the Gould & Curry 1900 level, the incline of the Imperial and the northeast drift run along the face of the branch dyke in the 2001 level of the same mine. The dyke itself is perhaps somewhat hotter than the average of the rock, but the hottest points are not in its mass but at its contact with diorite and propylite. Here, as pointed out in the geological description, it is usually accompanied by a sheath of shattered propylite, a few feet in thickness, in which respect it resembles the whole family of dykes wherever found. This sheath of broken rock is not found everywhere, which accounts for the fact that the inclines are not all hot, though most of them lie near or in the dyke.

Hot belts are found at the contact of the diorite and propylite in the Virginia mines. The diorite is itself in active decomposition in places, and mines which have carried drifts in or near it are sometimes very hot. The Julia has explored a quartz seam, which appears to lie entirely in the diorite, and this has proved to be one of the hot belts, but it is also near the dyke. This apparent concentration of the heat in the line of contact of two rocks is not due to any thermal or electro-thermal action, but depends entirely upon the presence of the dyke with its casing of broken rock.

Water Temperatures. These vary considerably, and are very much affected by the conditions under which the observation is taken. In the Julia 1800, on the west side of the dyke was a small stream of water, the size of the finger, in which, when the thermometer was held in it in immediate contact with the rock, the reading was found to be 156° F. ; but after running a couple of inches over a board where it spread out in a thin stream, the reading was five degrees lower. The water standing in a winze on the same level showed only 123° F., but on the other hand a great body of water which broke into the 2000 level in 1879 is reported to have had a temperature of 158°.

The vast body of water which has filled the Savage and Hale & Norcross mines for three years, and from which 306,572,228 gallons of water have been pumped by the Norcross alone, without reducing its level finally more than forty-five feet, gave me a temperature of 154° Fahrenheit. Even after being pumped to the surface through an iron pipe exposed, in the shaft of the Hale & Norcross, to a descending current of fresh air for more than a thousand feet, and then flowing for one or two hundred feet through an open sluice in a drain-tunnel which discharges into a measuring-box, the water in this box was found to have a temperature of no less than 145° Fahrenheit.

In this case the water was confined in its long journey to the surface, and the cooling effect of evaporation was prevented. But a small stream which came from the hot crosscut on the Crown Point 2000 level had a temperature of only 127° F., though the air was the hottest observed in the mines (150° F.). I consider all temperatures taken in standing water, or running streams at a distance from their source, to be of small significance, and I have the impression that the water *in the rock* is always hotter than the air of the drifts. Whether it is hotter than the rock at the 2000 level and below, is a point on which there is no exact information. In the upper levels this was undoubtedly the case, the fact being reported both by the miners and by scientific observers.

Air Temperatures. The temperature of the air is subject to more fluctuations than that of the rock, for the simple reason that it is artificially supplied to the mine, and takes its heat entirely from the rock, water, and artificial sources. The amount of heat absorbed necessarily fluctuates with the distance to which it is carried, the quantity, velocity in the pipe, and its initial temperature. All of these elements of the problem vary within wide limits. The initial temperature of the air which supplies a particular drift will, for instance, depend upon whether it is drawn from the surface, the bottom of a shaft—where it is often cooler than above ground—or from some old air-way, where it has had time and opportunity to take up heat. But even under such variable conditions as these, the temperature of the air in new drifts, in fresh ground, and with no other air supply than that derived from a small fan-engine does not ordinarily fluctuate more than eight degrees. Perhaps the most common observation made was 108° F., and 116° F. was the maximum under these conditions. In this variation the length of the drift appears to be the most important factor.

This uniformity of temperature, under such changing conditions, is due to the well-known fact that the amount of heat absorbed from the walls of a drift or shaft in a mine depends upon the difference in the initial temperature of the air and rock. The greater this difference, the greater is the absorption, but as soon as the temperature of the air-current approaches that of the rock, the heat absorption proceeds much more slowly. The quantity of air and its velocity in the drift, both in the air-pipe and in the return current, is as uniform as possible throughout the mines.

In the Comstock mines it is the custom, without exception, to blow the air to the header through galvanized iron pipes, the diameter of which is usually from eight to twenty inches. The size most used is eleven inches in diameter, and the usual amount of air blown is about seven hundred cubic feet per minute, this being the supply for two to six or more men, working in one or two "headers." In most cases the air is not sent down from the surface, but is taken from some point in the incline or at the bottom of the shaft. Its temperature may be assumed at about 85° or 90° F. in summer, though it is sometimes higher than this. Its velocity in the air-pipe is not very far from one thousand feet per minute, and the return velocity through the drift is only between thirty five and forty feet per minute. From these data it will be seen, that in the pipe we have about fifteen or twenty degrees of heat added to the air, in a period of time varying from one half minute to two minutes. The iron of the pipe is so thin and its conductivity so great that practically we have a slender current of air moving through a body of hotter air. Even this statement of the case does not exhibit all the opportunities for absorbing heat which are forced upon the air.

The iron receives heat both by immersion in the hot air, and by direct radiation from the still hotter walls. The currents confined in it must be thrown against its sides by eddies and bends, and the air is thus made to take up heat by contact as well as by the transmission of heat rays through it. It is probably to this cause that the uniformity of the air temperatures obtained at the headers may be attributed. They depend almost entirely on the heat of the ground there, which is tolerably constant for a given depth, and upon that of the return current, which is always very slow. The temperature of the air at the fan seems to be the least factor in the problem.

Most of the readings given in the table are below 100° F., but these were always taken above the 2000 level. Below that depth the air is invariably above 100° F., and as before said varies usually between 108° and 116° F. The effect of hot spots is not exhibited by the table. Even the abnormal temperature of the Crown Point 2000 crosscut cannot be quoted, for it was taken in an abandoned work with no ventilation. Still, that was undoubtedly a hot spot, and the crosscut was reported to cut a dyke. The Gould & Curry 1900 south drift with its air temperature successively reported, as its length increased, at 123°, 126°, and 128° F., is another.

On the whole it may be stated as the rule of the lode at the 2000 foot level, that under ordinary conditions, drifts that do not exceed two or three hundred feet in length are not above 110° or 112° F. in temperature, and more often they are below this. But when the length increases to 1200 and 1500 feet the temperature may rise to 116° F. without any other change in the circumstances.

Amount of heat withdrawn from the rocks.—The quantity of water pumped from the mines in 1877 must have been as much as 350,000 or 400,000 tons a month. If its temperature is assumed to be 135° Fahrenheit, and the average temperature of the air for the year 50° Fahrenheit, we have in the year, say, $350,000 \times 12 = 4,200,000$ tons of water raised eighty-five degrees in temperature; or as the usual expression is, $4,200,000 \times 85 = 357,000,000$ ton-heat units have been absorbed by the water. The heating power of pure carbon being 14,544 units, the abstraction of heat in the mine waters is equivalent to the complete combustion of 24,546 tons of carbon yearly.

In the first chapter it was shown that the upcast shafts of the lode discharged 288,630 cubic feet of air per minute, on a July day in 1877. As this was in summer, and two old shafts which are still effective as upcasts were not measured, it is probable that the average of the year may be taken at 300,000 cubic feet per minute, or eleven and a quarter tons. The air had an average temperature of 92° F. The total quantity for a year would therefore be 5,913,000 tons, and its elevation of temperature forty-two degrees, the yearly mean in the Comstock region being about 50° F. The specific heat of air being 0.2375, we have $5,913,000 \times 42 \times 0.2375 = 58,982,175$ F. ton-heat units for the amount of heat absorbed by the air. This corresponds to the heat obtained by the complete combustion of 4055 tons of carbon.

By these two causes of heat abstraction the rocks lose as much heat as 28,601 tons of carbon can yield. If we translate these theoretical quantities into the more commonly observed industrial results of burning anthracite coal, and estimate the practical return at 7500 heat units per ton, we shall find that the ordinary operations of mining abstract as much heat from these rocks as 55,472 tons of anthracite produce in the best manufacturing usage.

Such calculations as these cannot claim scientific accuracy, and they are presented here merely to show that the quantity of heat given out by the rock is very much in excess of any thing that can be attributed to the heat from candles, muscular action, the slow decomposition of timbers and other sources of heat in mines. They indicate in a striking manner the elevated temperature of the great mass of rock in which the Comstock mines are excavated. In these calculations no account has been taken of the heat absorbed by the expansion of ten or twelve thousand cubic feet of air per minute from sixty pounds' pressure, or of the vast absorption of heat by the vaporization of the moisture with which the air discharged from the mines is heavily loaded. The expenditure of candles is said to be 10,000 daily, and the number of men underground is about 2700.

Records of the Yellow Jacket Mine.—Fortunately for the purposes of this examination, Captain T. G. Taylor, former Superintendent of this mine, had placed thermometers in its main airways, where readings have been taken twice a day, and the records begin with December, 1876. The Yellow Jacket is a downcast mine, and the air-current passes down the vertical shaft to the 1119 level, thence down the incline to the 1531 level, along that level through the main drift to the south winze, and down this winze to the bottom of the mine, which was the 2200 level when I visited it. On its way from the 1531 it sends "splits," or portions of the air-current, along the main drift on the 1732, 1935, and 2040 levels to the north winze, which is parallel to the south winze, and 413 feet distant. All these several currents are reunited in the north winze, which is the upcast, but the air does not return to the surface in this mine, being sent through long drifts to the Imperial and Bullion mines, both north of the Jacket, and both exclusively upcast.

This arrangement of ventilative currents on parallel lines at different depths is precisely what would be chosen for special experimental purposes. Captain Taylor placed Fahrenheit thermometers of the common kind with japanned tin cases at the surface, foot of the vertical shaft (1119 level), 1732 south and north winzes, 1935 north winze, and 2040 south and north winzes. Those hung at the south winze measure the increase of heat in the air in descending that winze, while those which are placed at the north winze measure the gain in temperature during the passage of the air through the 413 feet of drift on each level. These levels are all above the present working centres of the mine, and as they are not occupied except at the change of shifts and the occasional passage of a foreman, they present a favorable opportunity for the study of the single problem of heat absorption from rock surfaces by moving currents of air. The rock is hard, and frequently untimbered for long distances, and the only complications in the problem, in addition to the momentary occupation spoken of, are the constant burning of one, and sometimes two candles in each drift, and the movement of newly-broken rock through the 1732 foot level during part of one shift.

The observations were made morning and evening at 6 o'clock, and the readings are given in the following table. The omissions are due to the accidental destruction of the tally boards, and they are so numerous that a proper discussion of these interesting facts must be postponed until a continuous record is obtainable.

TABLE I.

YELLOW JACKET MINE.—MORNING TEMPERATURES, 6 A.M.

	Surface.	1,119 feet. Station.	1,732 feet.		1,900 feet. N. Winze.	2,040 feet.	
			S. Winze.	N. Winze.		S. Winze.	N. Winze.
December, 1876..........	.....	59·27°	80·23°	92·99°	.....	.....	.....
January, 1877.........	.....	52·55	73·42	86·90	.....	85·35°	93·22°
February, “	.....	49·75	76·99	83·71	.....	86·59	93·99
March, “	.....	53·81	78·13	89·20	90·29°	83·68	94·99
April, “	.....	49·87	77·40	88·13	89·97	85·90	93·77
May, “	.....	53·77	83·42	90·45	90·99	83·39	93·61
June, “	56·07°	57·40	79·39	91·47	93·27	88·26	93·63
July, “	.....	.....	84·00	.....	94·07	.....	.....
August, “	.....	.....	83·23	.....	94·50	....	.....
September, “	56·67	60·80	81·86	91·67	96·60	88·37	92·13
October, “	46·10	55·13	73·65	90·44	92·07	83·23	88·36
November, “	39·90	....	76·53	.....	88·50	81·27	87·23
December, “	35·84	.....	.....	.....	.....	.....	.....
January, 1878.........	33·39	.....	.....	.....	.....	.....	.....
February, “	33·93	.....	.....	.....	.....	.....	.....
March, “	39·84	.....	.....	....	.....	.....	.....
April, “	42·37	.....	....	.....	.....	.....	.....
May, “	51·10	.....	.....	.....	.....	.....	.....
Average...........	43·52°	54·71°	79·02°	89·44°	92·25°	85·11°	92.33°

TABLE I.

YELLOW JACKET MINE.—EVENING TEMPERATURES, 6 P.M.

	Surface.	1,119 feet. Station.	1,732 feet.		1,932 feet. N. Winze.	2,040 feet.	
			S. Winze.	N. Winze.		S. Winze.	N. Winze.
December, 1876	.....	59·20°	80·84°	90·92°	.....	.....	.....
January, 1877	.....	50·77	77·82	86·10	.....	83·23°	93·36°
February, "	.....	.....	76·71	84·03	.....	86·82	93·43
March, "	.....	55·52	74·07	88·58	90·29°	86·68	95·00
April, "	.....	52·83	77·57	88·33	89·93	85·87	93·80
May, "	70·47°	61·50	79·42	91·77	93·03	87·16	93·48
June, "	70·33	61·50	79·40	91·77	93·03	88·20	93·73
July, "	.....	.....	84·16	.....	94·29	.....	.....
August, "	.....	.....	83·42	.....	94·29	.....	.....
September, "	69·13	62·76	81.82	91·11	96·67	87·90	92·00
October, "	54.55	57·30	72·99	91·00	92·10	83·32	88·58
November, "	45·43	.....	77·40	.....	89·50	81·13	87·23
December, "	39·58	.....	.....	.....	.....	.....	.....
January, 1878	38·84	.....	.....	.....	.....	.....	.....
February, "	37·61	.....	.....	.....	.....	.....	.....
March, "	44·87	.....	.....	.....	.....	.....	.....
April, "	52·37	.....	.....	.....	.....	.....	.....
May, "	60·77	.....	.....	.....	.....	.....	.....
Average.	53·09°	56·67°	78·78°	89·29°	92·57°	85·59°	92·29°

In the following table are given some additional temperature readings which are separated from the foregoing for the reason that they are not used in the few calculations I have ventured upon, and also because the localities have been changed by the removal from the old works to the new shaft. The latter starts from a somewhat higher point than its predecessor, so that the 2280 level in the new shaft corresponds with the old 2200. When this shaft reached a sufficient depth, the old south winze was discontinued, and its readings end with January, 1879. Its place is taken by the new shaft, which is downcast, and the temperature of the inflowing air is measured first at the station by the shaft, and again at the north winze after flowing through the connecting crosscut. On the 2500 level the distance between these two points is 569 feet, and it varies as the shaft descends.

TABLE II.

Yellow Jacket Mine.—Morning Temperatures, 6 A.M.

	Surface.	2,040 feet.		2,280 feet.		2,400 feet.	
		S. Winze.	N. Winze.	Station.	N. Winze.		N. Winze.
August, 1878	.....	80·64°	86·42°	.....	.....	......	.....
September, "	.....	79·23	85·13	.....	.....	......	.....
October "	.....	77·42	83·74	.....	.....	......	89·84
November, "	.....	75·93	82·50	.....	.....	......	89·77
December, "	.....	72·20	79·29	.....	.....	......	87·80
January, 1879	.....	70·03	77·68	.....	.....	......	86·26
February, "	.....	.....	.....	74·48°	91·44°[*]	......	.....
March, "	40·00°	.....	.....	69·58	83·06	......	.....
April, "	45·96	.....	.....	70·37	83·70	......	.....
May, "	43·77	.....	.....	71·00	81·71	......	.....
June, "	57·00	.....	.....	72·80	82·30	......	89·15
Average............	.....	75·91°	82·46°	71·65°	84·44°	......	.....
Average of 4 months.	.....	.....	.....	70·94	82·69	......	.....

TABLE II.

Yellow Jacket Mine.—Evening Temperatures, 6 P.M.

	Surface.	2,040 feet.		2,280 feet.		2,400 feet.	
		S. Winze.	N. Winze.	Station.	N. Winze.		N. Winze.
August, 1878	.....	81·78°	86·50°	.....	.....	......	......
September, "	.....	75·87	85·30	.....	.....	......	......
October, "	.....	77·42	83·81	.....	.....	......	......
November, "	.....	76·76	82·60	.....	.....	......	......
December, "	.....	72·27	79·52	.....	.....	......	......
January, 1879	.....	70·06	77·16	.....	.....	......	......
February, "	.....	.....	.....	74·29°	90·81°[*]	......	......
March, "	47·52°	.....	.....	69·23	83·31	......	......
April, "	46·10	.....	.....	70·67	82.87	......	......
May, "	49·74	.....	.....	70·93	81·71	......	......
June, "	64·30	.....	.....	72·70	82·40	......	......
Average.............	.....	75·69°	82·48°	71·56°	84·22°	......	......
" 4 months...	.....	.....	.....	70·91	82·46	......	......

It is to be regretted that this record is not more complete. Interesting facts are hinted at by the few co-ordinate observations at the surface and foot of the vertical shaft (1119 feet). As shown by the morning temperatures, the night air gained heat during the summer in its descent, and the day air lost heat in the shaft, as the 6 P.M. observations show. But in October the day air gained heat, and that is probably true for the winter months. In fact, while the surface temperature for the whole twenty-four hours fluctuates between 33·39° and 70·47°, or over a range of 37·08°, the range is only 13·01° in the mine, or from 49·75° to 62·76°. The shaft is therefore an efficient equalizer of temperature, and this action is evidently due to its moisture. It maintains a standing dew point, which is ineffective at night, when the atmosphere is already loaded with moisture, and also in the winter. But in the daytime and in summer, when the air has a high capacity for aqueous absorption, the vaporization of moisture in the shaft cools the air and establishes artificial conditions that resemble the natural state of things at night. In this manner the shaft acts as a regulator, which preserves the remarkable uniformity noticeable in the mine temperatures throughout the year. Irregularities there are, but they are not comparable to those of the surface. At the surface the variation between extremes in the morning observations was 23·28°, and in the evening it was 32·86°, but at the depth of 1119 feet these variations were only 11·05° and 11·99°, respectively. The observations at the two points are not co-ordinate, but the annual variation would probably be found to sustain this relation of the several means. It would be possible, under these circumstances, to obtain a clear idea of the function which a great shaft fulfils in the work of ventilation, but for such a purpose an unbroken annual series of observations is necessary. In May and June, 1877, the average refrigeration of the day air in the shaft was 8·90° Fahrenheit, and if the air supply amounted to 18,000 cubic feet, or 1356 pounds, per minute, we should have $1356 \times 0{\cdot}2375 \times 8{\cdot}90 = 2866{\cdot}2$ Fahrenheit-pound heat units per minute for the value of the cooling action of the shaft in those two months. During the night the air was slightly warmed in June.

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[*] The connection between the 2,280 station of the new shaft and the 2,200 level of the old works was made in February, 1879. Before that was accomplished the thermometer in the shaft marked 105° but during 18 days following sank to 86°. The readings for this month are therefore abnormal.

Only two of the levels have thermometers at both winzes—the 1732 and 2040—and our further study of the phenomena must be confined to them. The omissions in the record also restrict the comparison to eight months—from January to October, 1877, with July and August excepted. The records in these eight months show that the air current, in moving 413 feet, from the south to the north winze, gained in temperature as follows :

ON THE 1,732 LEVEL.

Morning	89·00° − 78·03° = gain	10·97°
Evening	89·09° − 77·45° = gain	11·64°
Average		11·30°

ON THE 2,040 LEVEL.

Morning	92·96° − 85·60° = gain	7·36°
Evening	92·67° − 86·15° = gain	6·52°
Average		6·94

The air current entering the mine July 2d, 1877, was measured and found to be 18,140 cubic feet. On the 1732 level the "split," or secondary air current, was found to contain 7200 cubic feet. It is quite probable that the quantity of air passing through the two levels is not the same; but for the purpose of direct comparison, we may make an arbitrary equal division of the main current between the three levels, and assume that each one receives 6000 cubic feet, or 452 pounds, of air per minute. The heat capacity of this quantity corresponds to that of 107·35 pounds of water. We then have for the amount of heat absorbed on each level per minute:

In the 1732 level, $452 \times 0{\cdot}2375 \times 11{\cdot}30 = 1213$ pound Fahrenheit heat units.

In the 2040 level, $452 \times 0{\cdot}2375 \times 6{\cdot}94 = 745$ pound Fahrenheit heat units.*

The different absorption on the two levels is explained by the fact that the air gained 8·14° in temperature in the inclined south winze in its journey of about 520 feet from the 1732 to the 2040 level.

The heat of these mines is so extraordinary that it is worth while to show again the calorific power of the rock, as exhibited by comparison with the most familiar example of oxidation. On these two levels the data above given show that the heat absorption is equal to the combustion of—

	CARBON.	ANTHRACITE.	
On the 1732 level,	0·083	0·161	pounds per minute.
On the 2040 "	0·051	0·100	" " "

The effect upon the air current in the 1732 level is therefore the same as if

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* All the quantities in these calculations differ slightly from those published in a paper on the "Heat of the Comstock Mines," read before the American Institute of Mining Engineers, where a six months' series of observations was used instead of an eight months' term.

29·9 pounds of pure carbon were completely burned at hundred foot distances every day; or the same that four fires of anthracite coal, distributed at the same distances and burning 56 pounds each in twenty-four hours, would produce, if the useful effect of the coal is estimated at the somewhat high figure of 7500 units. At the time these observations began this drift had been opened and exposed to the cooling action of a constant air current for more than a year.

Only one candle burns constantly in the drift, and the travel does not amount to more than two hundred trips of one man in one direction in twenty-four hours. The effect of this travel is limited to the change of shifts and the transport of rock and timber, both of which are concentrated in short spaces of time. A hoisting engine in the winze uses about 9000 cubic feet of compressed air daily, at fifty pounds pressure, which is quite sufficient to neutralize all the heat that can be obtained from the transitory presence of men in the drift. To further show how completely this source of heat may be neglected, it is enough to say that only the morning observation, at 6 A.M., is made at or near the time of this travel.

In other respects I have not observed any circumstances which throw serious doubt upon the thermometer readings. The instruments are not standards, it is true, but they are properly hung on timbers, and usually with ten or twelve inches of wood or air between them and the rock surface. Whenever compared with one of the Survey thermometers, hung in the centre of the moving air current, they have not shown a variation of more than one degree. The daily readings are quite uniform, the fluctuations of more than one degree not exceeding twenty-three in a series of about 360 observations. The highest fluctuation noticed is three degrees.

The circumference of the drift is about twenty-eight feet, outside of timbers, the dimensions being six feet six inches at bottom, five feet six inches at top, and eight feet high, when the timbers are twelve inches thick. The maximum area of the walls is therefore 413 × 28, or 11,564 square feet, and the heat radiation amounts to 151 pound units per square foot in twenty-four hours.

It is to be regretted that the casual and frequently intermitted observations on heat, which were all that pressure of other duties permitted me, were not so arranged as to ascertain the rate of transmission in these remarkably hot rocks. Only one observation of the surface temperature in a drift was made. With a temperature of 136° F. in a drill-hole bored in the freshly exposed rock of the heading, and an air temperature of 110½° F. in the drift, a thermometer laid on a projecting point of the wall, fifteen or twenty feet from the heading, showed 123° F. This surface must have been about four days old. The reading gives a certain amount of precision to the expression of a fact well known to the miners—that the rock cools rapidly in the first few days of exposure.

Rate of Transmission.—But even in the absence of positive experiments upon the rate of transmission it is possible to show that this rate is much too high to be accounted for by mere conduction. Sir William Thomson's discussion of Professor Forbes's observations in the trap rock of Calton Hill, Edinburgh, shows that if a plate of this material, one foot thick, had one side kept at a temperature constantly one degree better than the other side, the heat which would pass through it in one year would be sufficient to raise 144·1 cubic feet of water one degree in temperature, or 0·3863 cubic feet in twenty-four hours But the amount of heat transmitted varies inversely as the thickness of the plate, and it would be necessary to ascertain accurately the heat at different depths, in the same locality, before the true rate of transmission in the Comstock drifts could be settled. While this cannot be done at present, a comparison of the heat absorption in the 1732 and 2200 feet levels of the Yellow Jacket mine shows a rate so much in excess of that derived by calculation that no allowance for errors of observation can lessen the positiveness of its evidence. Between these levels there lies a stratum of rock 468 feet thick, in the vertical direction, and nearly one half more if the inclination of the rocks is followed. Assuming that the lesser thickness represents the path of transmission, we have a rock layer 468 feet thick with its lower surface constantly maintained at a temperature which is, taking the mean of two readings, 138° F., and from the walls of a drift opened at its upper surface there is a constant absorption of heat by an air current, amounting to 151 pound heat units per square foot and twenty-four hours, this being the mean of an eight months' period of observation.

Since the transmission of heat through a one-foot stratum of rock, having a difference of one degree between the temperature of its upper and lower surfaces, is sufficient in twenty-four hours to heat 0·3863 cubic foot of water, one degree F. for each square foot of surface, we have, $0 \cdot 3863 \times 62 \cdot 447 = 24 \cdot 123$

pound heat units, transmitted through eruptive rock in twenty-four hours, per square foot of surface, under these conditions. For a stratum 468 feet thick, the transmission, being inversely as the thickness, would amount to 0·0515 pound heat units per square foot for each degree of difference in temperature between the upper and lower surfaces.

In a similar way we can estimate the temperature necessary on the 2200 foot level, to maintain, at Professor Thomson's rate of transmission, the heat absorption found by observation in the 1732 level. To do this it is obviously necessary to consider the whole area of the latter drift as being spread out so as to form the upper surface of the stratum. Its heating power has been found to be 151 units per square foot and twenty-four hours, and by the accepted rate of transmission this would require on the 2200 level a temperature of 151 ÷ 0·0515 = 2932 degrees F. Faulty as the observations upon which this calculation is based necessarily are, the testimony of such a result is unimpeachable. Conduction alone cannot account for the effects observed.

The existing temperature of the rock in the upper levels is unknown, but, fortunately, we are able to apply this form of comparison also by means of an old observation made by Mr. Charles T. Hoffmann, formerly of the California Geological Survey, on the 1531 level of this mine in 1873. At that time the work on this level was in progress, and he found the temperature to be

Rock, dry-hole in upper part of the header	123° F.
Rock, wet-hole in lower part of the header	120° F.
Air in the drift	102° F.

Taking the difference between the heat of the dry-hole on this level and that found on the 2200 level, or 138°—123° = 15°, we have an increase of fifteen degrees in 670 feet of depth, or an average rate of increase amounting to one degree for 44·67 feet. This would give a total increase of nearly 4·4 degrees between the 1531 and 1732 level, and the temperature of the latter would be that of the 1531 *plus* the increase; or 123° + 4·4° = 127·4°. Therefore the difference between the normal temperature of the rock on the 1732 and the 2200 levels is nominally 138°—127·4° = 10·6°. Our rock stratum of 468 feet thickness accordingly has its lower surface constantly maintained at a temperature 10·6° higher than its upper surface. Its normal rate of transmission being 0·0515 pound Fahrenheit heat units, per square foot and twenty-four hours, the radiation on the 1732 level should be 0·0515 × 10·6° = 0·5459 heat units. This is only 0·0036 of that which is actually taking place.

This enormous difference (151—0·5459) between the results of calculation and of direct observation is sufficient to dispel the natural doubt which must rest upon estimates based upon a single observation. But in regard to the temperature assumed for the 2200 level (138° F.), it is to be remarked that this is a maximum, all readings in other mines being somewhat lower. Since my visit to the mine, Mr. James, the present superintendent, has found the following rock temperatures: 2400 level, old works, 152°; new shaft, 2408 feet depth, 132° and 144°; 2670 feet depth, 155° F.

The case may also be stated in another way. If the transmission through a one-foot stratum is 24·123 pound units per square foot, in twenty-four hours, for each degree of difference in temperature, and the radiation on the 1732 level is 151 pound units for the same surface and time, it is evident that a rock stratum having its lower surface kept 10·6 degrees hotter than its upper surface, could at this rate not exceed a thickness of 1·69 foot. For a stratum of this thickness would transmit 14·3 pound heat units per square foot in twenty-four hours, and 14·3 × 10·6° = 152 units for the radiation. Instead of the height of 468 feet between the 2200 and 1732 levels, the law of transmission would not admit of a stratum more than twenty inches thick between the surface where a daily radiation of 151 foot-pound heat units is in progress and the surface where an excess of 10·6° F. is maintained.

From these several modes of comparison we obtain the following conclusions:

1. Assuming the Comstock propylite to have the same rate of transmission as the Calton Hill trap, the stratum of rock 468 feet thick between the 2200 and 1732 foot levels of the Yellow Jacket should transmit in twenty-four hours 0·0515 pound Fahrenheit heat units per square foot for each degree of difference in the temperature of the two levels.

2. The actual difference of temperature, taking observations made under similar circumstances, was about 10·6° F. before the rock had time to cool off, and the amount of heat that should be transmitted per square foot of surface in twenty-four hours may be estimated at 0.5459 pound heat units, by the Calton Hill rate of transmission.

3. In a drift opened on the 1732 level, after an exposure of more than a year, during which the air temperature in the drift fell from 102° to 89·44° F., the amount of heat transmitted is found to be 151 pound heat units per square foot in twenty-four hours. The actual heating power of the rock at the depth of 2200 feet is therefore $151 - 0{\cdot}5459 = 150{\cdot}4541$ pound units, or nearly 300 times, greater than the calculated heating power.

4. If we estimate the temperature required on the 2200 level to maintain the observed heating effects on the 1732 level, it is, by Sir William Thomson's formula, 2932° F.

5. On the other hand, if we estimate what thickness of rock would permit the observed temperatures on the 2200 level to produce the observed heating effects on the 1732 level, under the Calton Hill rate of transmission, we find that a stratum of 1·69 feet thickness satisfies the conditions.

The quantities obtained in these calculations will undoubtedly be subject to considerable corrections when observations are made with more accurate instruments. It is not intended here to give the impression of exactitude in this respect, but it is considered that the observations and calculations made are sufficient to establish the certainty that some other cause than mere transmission or conduction of heat must be in operation in Comstock ground.

Source of the Heat.—The extraordinary phenomena of these heated rocks have been exhibited, perhaps with tedious detail, in the foregoing pages, and the source of this wonderful heat production will now be considered. It has been my endeavor throughout this work to avoid the pursuit of theories, and allow the observed facts to work out their own conclusion. This course will be followed now, and in presenting a new explanation of the cause of heat phenomena within the earth's crust, absolute dependence will be placed upon the facts which can be locally observed in the Comstock region, without regard to the criticism which observations at other points may bring upon it.

The acknowledged sources of heat within the earth's crust are now two in number: first, radiation from a melted or hot interior, and second, oxidation of certain elements. To these may be added Mr. King's opinion that the Comstock rocks are heated by deep waters.

Wherever eruptive or plutonic rocks are found it is quite common to witness evidence, in the breaking out of hot springs, that heat agencies are still active within them, and this phenomenon is so frequently observed that hot springs are often referred to as the last phase of eruptive activity. The heat in the Comstock and other mines similarly situated is quite generally spoken of, for instance, as the feeble remnant of a temperature that once reached the point of rock fusion, but a consideration of the circumstances under which the lode rocks were laid down, and the time which has elapsed since their ejection, seems to be conclusive against this hypothesis.

Just how many years have rolled over this region it is of course impossible to say, but the following facts show that their number is too great to allow us to attribute the heat to a remnant of the original heat of fusion retained in these thin strata.

First. The mines are opened in the lowest and first ejected layers of propylite, and in the diorite, which is referred to a geological epoch earlier than the former rock.

Second. The lapse of time has been sufficient to allow the gradual building up of ten thousand feet of propylite, and probably several thousand feet of andesite in repeated eruptions, the deposition of hundreds of millions of tons of quartz, the ejection of two or three thousand feet of trachyte, also in successive eruptions, and finally the deposition of a second series of large quartz bodies carrying silver and gold.

None of these facts enable us to fix even an approximate number to the years which were required to perform the great work. As to the eruptive periods, not even a wild guess from them is possible, and the chemical epochs offer us no better basis for enumerating the years, but the latter do permit us to establish on firm ground the conclusion that, under the existing circumstances, none, or but a small portion, of the original heat of eruption can be retained in the rocks.

The total thickness of the quartz deposits has been placed in the foregoing pages at 500 feet, and from the known solubility of silica in water we may form an idea of what degree of concentration the siliceous waters might have attained under the most favorable circumstances. Whatever rate is selected, it would be hard to place within a moderate period of time the formation of a solid quartz seam 500 feet thick, the removal of an almost equal thickness of propylite by means which necessitate the combining action of a part of the [illegible] in the water, and, finally, the removal of another vast mass of andesite by process in which the siliceous waters also played a prominent part. This [illegible] work of the waters defeats any possible conception of rapid action by the agency of concentrated waters. Even under the most favorable circumstances thousands of years would be required for the work; and if we cease to accept an extravagant concentration of the waters, and allow only such a proportion of silica as we know to be dissolved in hot terrestrial waters at present, we shall arrive at a period of time which is to be reckoned probably by hundreds of thousands of years for the chemical phenomena alone.

The presence of this flood of waters is itself a proof that true eruptive heat cannot remain in these rocks, for that would have been extinguished by the deluge which passed through the strata at so many points. Whatever original heat the strata now retain must be solfataric and not igneous; and any theory which attributes the existing state of things to residual heat must account for the retention of high temperature in rocks which were not much above boiling heat, and have for ages been penetrated by great quantities of cooling water from the atmosphere. The amount of rainfall which would sink to the depth of 2000 or 5000 feet in the period which has elapsed since Miocene time would be sufficient probably to extinguish any remains of mere solfataric heat still residing in the rocks, unless it was supported by radiation from deeper sources or by some continuous process of heat generation in the rocks themselves.

The presence of organic growths at several horizons in the propylite is equally strong evidence against the retention of high temperature in the rocks. Whether the "coal" is always derived from trees or sometimes from smaller plants, as the compressed form of the little beds may indicate, the surface upon which it grew must have been of ordinary terrestrial temperature, probably lower than the same spots now exhibit when uncovered by mining.

Quite as strong is the testimony derived from the mode in which the rocks were built up. The stratification of the propylite shows that there was no pouring out of a deep flood of lava in the bosom of which a red heat might be maintained for years, and even ages, for lack of sufficient radiation to cool the rock. On the contrary, the streams were thin, and the occurrence of charred trees proves that there were also long periods of rest. It is at least doubtful whether these streams retained their heat longer than ordinary volcanic currents. The allotment of the diorite to Jurassic time is of especial interest in this connection, for the drifts in this rock are among the hottest on the lode. The age of the rock seems to have no relation whatever to its temperature, and in the mines the observer can walk from Jurassic to late Miocene depositions without affecting the thermometer in the slightest. This could not be the case if the heat were only residual. The diorite in which the mines are worked was the old surface, and even if it is eruptive in origin it had time to cool so completely that the succeeding layers of propylite would hardly have warmed it up again to their own temperature. The propylite layers which contain most of the existing mines are also at the bottom of the series, and if eruptive heat had anything to do with the phenomenon under discussion they ought to be the coolest.

Finally, the observable heat phenomena forbid the probability of the theory under discussion. The presence of hot belts and cold belts is constantly demonstrated, and the thermometer readings at different points vary so much that it is impossible to average them as they are taken. The observer is forced into a classification of them, and in making it he will find himself at a loss to imagine the circumstances under which mere conduction can produce such extraordinary fluctuations.

In brief, the phenomena of the Comstock do not admit even the possibility that the heat encountered is a remnant of ancient eruptive heat.

That oxidation is not the cause of the heat is proved by inspection of the rocks. Pyrite is the only unoxidized mineral they contain, and the quantity of that is extraordinarily small for the neighborhood of a great metalliferous lode. All of them, diorite, propylite, and andesite, contain pyrite, but chiefly in extremely small, almost microscopic crystals. Every slide placed under the microscope shows them; but it is precisely in this situation that their extremely small proportion to the remainder of the mass is exhibited. Microscopically the pyrite is insignificant. It is to be remarked also that the hot portion of the lode rocks is not within that zone near the surface, which betrays the action of oxidation. There the mines were not hotter than confined works of this character are apt to be, and the source of their somewhat elevated temperature was not the rock as it is now. As the heat increased, oxidation was left behind. This is proved by the fact that gypsum, one of the essential results of oxidation when applied to metallic sulphides enclosed in feldspathic rocks, is found only in the smallest quantity in the hot ground. It is everywhere present, but covers the rock surfaces only with the finest sheen which the finger can rub off. Its quantity is absolutely insignificant in the lower or hot area; and this fact should be sufficient alone to demonstrate that heat is not now derived from the oxidation of metallic sulphides. On the other hand, gypsum was found in considerable quantities within 600 feet of the surface, where a large part of the quartz was reddened by iron oxide.

But more positive proof is found in the composition of the mine waters, a few analyses of which are given in the following table:

Analyses of Water from the Comstock Lode, taken at Different Levels.

	Savage. 600 feet. Grains per gallon.	Gould & Curry. 1700 feet. Grains per gallon.	Gould & Curry. 1800 feet. Grains per gallon.	Hale & Norcross. Grains per gallon.	Ophir. 450 feet. Grains per gallon.
Silica	1·77	2·21	4·025	3·500	2·20
Sodic chloride	0·13	0·04	1·162	1·327	0·60
Calcic sulphate	29·40	14·35	16·683	22·532	10·01
Magnesic sulphate	1·77	.....	......	......	2·93
Sodic carbonate	0·91	.....	......	18·518	4·10
Potassic carbonate	7·56	6·42	26·199	8·342	.....
Magnesic carbonate	2·98	.....	......	......	2·82
Alumina and Ferric oxide	0·05	trace.	trace.	trace.	traces.
Potassic sulphate	....	.....	......	......	0·65
Sodic sulphate	....	.....	......	......	2·67
Loss	....	.....	......	......	0·27
Total	44·57	23·02	48·069	54·219	26·25

The Savage water was analyzed by Professor S. W. Johnson for Mr. King, and the Ophir water was analyzed by Mr. George Attwood. The other analysts are unknown. Mr. Attwood says of the Ophir sample: "Temperature 70° F. Flow 300 gallons per minute. Entirely free from any trace of precious metals. Mechanically suspended matter in one gallon of 70,000 grains, 14.84 grains. Total amount of carbonic acid, 23·30 grains. Specific gravity at 0° F., 1′ ·0007″. The Hale & Norcross sample is from the great body which filled that mine to the 1750 level.

A comparison of these analyses shows that the largest amount of sulphuric acid is found in those waters which were drawn from the zone of oxidation and drainage, occupying the upper 600 feet of the lode. It is interesting to compare with this the analysis by Mr. W. F. Rickard, F.C.S., of the water supplied to Gold Hill in 1866. This water was collected from the old tunnels which penetrated the surface outcrops in great numbers, and out of 19·74 grains of solid matter per gallon only 0·11 grain was a carbonate. All the remainder consisted of sulphates of lime, magnesia, and soda.

Of the solid matter in the Hale & Norcross water only 5·3 grains were sulphur, a quantity which would combine with 4·7 grains of iron to form pyrite. Favre & Silbermann found that the heat produced by the transformation of iron to the protoxide by the wet way was 1352 centigrade units, and writers on the blast furnace have taken the heat produced by the peroxidation of this metal at 1780 centigrade units (Bell) and 1887 centigrade units (Gruner). As the iron is eventually deposited as ferric oxide in the rocks, we may assume the higher number in our calculations. Then the heat produced by this change would be for each gallon of water 4·7 × 1887 = 8859 centigrade grain units. Bell also accepts 2500 C. units as the quantity of heat resulting from the combustion of sulphur to the tritoxide state; or for the gallon 5·3 × 2500 = 13,250 C. units. Total, 22,109 centigrade, or 39,843 Fahrenheit grain units. The temperature of the water being 154° F., we may consider 104° F. to be the increase of temperature over the yearly mean of Nevada (50° F.), and a gallon of 70,000 grains therefore represents an increment of 7,280,000 F. grain units of heat. Not much more than one half per cent of this can be accounted for by the sulphur contained in the water, and the amount left in the rocks as gypsum would add only an infinitesimal quantity.

From these calculations it is plain that oxidation of the pyrite represented by the sulphur in the water cannot account for the heat of the rocks, even when no allowance is made for the absorption of heat by breaking up the iron and sulphur compound. Whatever results oxidation may produce elsewhere, its effects in the Comstock locality are insignificant.

Mr. King, finding that the water in the upper levels was hotter than the rock, concluded that the latter was heated by the water; but he makes no attempt to account for the source from which the water derives its heat. On this account his hypothesis might be omitted from the present discussion. But the subject is important, and as I cannot agree with him, the reasons for rejecting this hypothesis will be given here. It is still true, as it was at the depth of

1000 feet, that the water is hotter than the rock. The 2200-foot level of the Hale & Norcross, where the water broke in, probably has a temperature of 130° to 138° F., while the water when tested by me showed a temperature of 154° F. In the Julia 1800 a small stream of water has a temperature of 156°, and though the rock is very hot here, it is probably not so hot as this. Such facts certainly appear to sustain Mr. King's supposition ; but an examination of the conditions under which the waters of the lode rocks exist will show that they can be explained in another way.

It is now well settled that the waters of the lode occupy strata of rock which are generally parallel with it, these strata being separated by clays, dykes, or solid strata which are impervious to water, and accordingly retain the liquid between them. The numerous long drifts run to the eastward cut these parallel strata in great numbers, and tap the water they contain, sometimes in formidable quantities. But in spite of the number of these drifts, it is probable that some bodies of water have never been drained, but remain in the country rock at levels much above the lowest workings of the mines.

The vast quantities of water which have again and again suddenly flooded one mine after another are evidence that the reservoirs which contain them are made up of shattered seams, for the undecomposed rock of this region is finely porous, and not coarsely porous. It could hardly contain as much water as an ordinary sandstone, and certainly it could not give up its fluid contents with any great rapidity when in its natural condition. These facts have been recognized for a long time in the Comstock, where there is now a settled conviction among intelligent observers that the great inflows of water come from shattered and decomposed seams, parallel with the lode, and sometimes of great thickness. The old idea that the country rock contains cavernous openings holding large bodies of water has been abandoned, in consequence of the proof afforded by more than a hundred miles of exploratory workings, that the enclosing rocks are singularly free from vugs and open crevices. Very few have been found in proportion to the ground penetrated.

When "water bonanzas" are encountered, it is quite a common experience to strike them *below* the highest point of their source, and the mine is often flooded by such an occurrence to the depth of several hundred feet. The case of the Savage and Hale & Norcross mines is in point. The water was first struck in the 2200 level of the Savage, and filled the two mines to the 1750 level, a height of 450 feet, besides filling the 2400 level of the Savage. The pressure which lifted the water through 450 feet of height cannot be attributed to the tension of any gas, for the emanations of gas in the mines have never been very forcible. The water of this flood gave off gas constantly, but not violently.

The head of 450 feet under which this water entered the mine, was steadily maintained for several months, during which new pumps were put in, when it was gradually overcome and reduced to less than 200 feet by vigorous pumping. But this labor was stopped in April 1879, to await the completion of a drain in the Sutro Tunnel, and during the period of rest, lasting several months, the water rose to within 45 feet of its highest point, and was still rising slowly. The removal of about 3,000,000 tons of water reduced the original head of 450 feet only to 405 feet. Such persistent maintenance of the head cannot be attributed to anything but hydrostatic pressure. The water undoubtedly came from a fissured seam which rose to within less than 1750 feet of the shaft mouth.

The temperature of this water was much above the observed temperatures in the upper levels, and it is upon similar occurrences in former years that Mr. King's hypothesis was probably based. But if we accept a deep origin for this flood, it is necessary to provide a pressure of about 200 pounds to the square inch *plus* a large amount for friction. Nothing in the behavior of the water indicates a pressure of gas as great as this, and it is difficult to imagine any other mode of raising water from depths which are unconnected with the systems of drainage on the surface.

If, however, we acknowledge that this is not subterranean but surface water, we bring less doubtful agencies into the problem. The highest point reached by the flood, 1750 feet below the collar of the Savage shaft, is probably not far from 300 feet below the level of the Carson River, the lowest point of grand drainage in the region, and it is quite possible that the great Savage water seam is so connected with channels of surface drainage as to derive its head from them. On such a supposition the water might be heated in its passage through the hot rocks. But this supposition gives no answer to the question of the source from which these rocks derived their heat; and though Mr. King's suggestion has been examined here as if it were an hypothesis of heat origination, it really does not go further than to indicate a method in which heat derived from some extraneous source may be carried into the lode rocks. The water could be heated by passing through long and tortuous channels leading through the rocks which underlie the Comstock diorite and propylite ; but this somewhat violent hypothesis is unnecessary, and the phenomena can be explained in a way that makes less formidable calls on the imagination.

Theory of Heat Production.—I consider that the foregoing facts make the rejection of all the explanations given a necessity, and I hold that the remarkable heat of the Comstock rocks is derived from a source still active, that this action resides in themselves, and that instead of the rock being heated by the water, the heat is entirely due to chemical combination between the rock and the water, the two playing an equal part in the process.

This process is kaolinization, by which the anhydrous aluminic silicate of the feldspathic and amphibolic rocks which form the only substance of the Comstock ground is altered to clay by combining with water. The water changes from the fluid to the solid condition, and in doing so the general law of solidification is obeyed, the molecular motion which had maintained its state of fluidity becoming sensible as heat.

This theory is advanced with confidence in spite of the disadvantage that no estimate can be made of the specific quantity of heat which is produced by the change mentioned. It rests now, as it did when first advanced (in my report to Lieutenant, now Captain, Wheeler, dated May 20th, 1878) upon the fact that the deeper Comstock rocks offer *no* sign of any other chemical action of later date than the second deposition of quartz ; and upon the further fact that the rocks of the region are frequently observed to heat up strongly when brought in contact with water.

The evidence of kaolinization to an enormous extent is everywhere present. Even when this action is least suspected, the rock gives evidence of alteration, and Mr. King, in picking what he describes (p. 27) as "normal propylite," "a typical specimen" for analysis, took one that contained no less than 6·53 per cent of water. It is doubtful whether it is possible to obtain within 1000 and even 2000 feet of the Comstock lode a specimen of true, unaltered propylite. Where the rock is least altered and still retains its characteristic appearance, it contains some water. One of the analyses gives 2·31 water, the lowest percentage reported in propylite from this region.

But aside from this unsuspected alteration of the firm and typical propylite, the rock contains vast masses of material that are the result of more complete hydration. The number and thickness of the clays have been sufficiently described, and also the magnitude of those seams which are solid rock when the miner breaks into them, and flaking clay after a few weeks' exposure to the air.

The direct evidence that heat is produced when water is brought in contact with these rocks is of constant occurrence in the mines, and is offered, in fact, whenever a pump breaks or is stopped for any reason, and water rises upon a partially decomposed seam. A case of this kind in the Caledonia is of more than ordinary interest, for the reason that this was a cool mine, both rock and water being but little above ordinary temperatures. The heat of the air in the drift was probably not above 90° F., but after lying twenty-four hours under water a very marked change took place. The water had reached a thick seam of the kind that is solid enough when dry, but swells with great force when wet. The twelve-inch timbers were all splintered, and the temperature of the level had risen probably to 110°, though no observation was taken. Still the fact of increased temperature and of increase from this cause alone was undoubted. Since that time the Julia, Savage, and Hale and Norcross mines have all been flooded and subsequently drained. The Norcross has a fine current of fresh air, and I have not observed any complaint of its condition, but both the other mines were reported to be extremely hot after their submersion. They were very much above their usual temperature, and work was frequently stopped to allow them to cool down. Such evidences cannot take the place of exact laboratory experiments, but they are just as incontestable proof of the fact of heat, and high heat, from kaolinization, as if we had its precise measure.

In the Comstock lode the source of the water which produces the remarkable heating of the rock is somewhat doubtful. The quantity that has been removed by the pumps is no more than meteoric sources could readily supply, but the filling up of the Savage reservoir during a three months' rest, and after the removal of 2,400,000 tons of water, to within less than 45 feet of the highest level can hardly be explained by meteoric causes, unless the drainage of

Carson Valley is beginning to affect the mines at their present depth. In searching for foreign examples to illustrate the theory of heat production, which I have suggested for the Comstock, it has been my good fortune to encounter an instance where the evident derivation of the hot mine water from the ocean removes every obscurity from the problem, and affords a perfectly filled-up record of the phenomenon.

In Vol. XLVI. of the *Philosophical Magazine* (May, 1873), Mr. John A. Phillips has given a very interesting and thorough discussion of the conditions under which hot water breaks into the Huel Seton mine in Wales, at a depth about 960 feet below the sea level. Out of 1012·35 grains of solid matter per gallon in this water, no less than 998·62 grains were chlorides, chiefly of sodium and calcium. Mr. Phillips carefully analyzed the rocks of the region, and proved that the chlorine could not have been derived from them. His conclusion was that the sea, four miles from the mine, had supplied the water. Under such circumstances, it is interesting to note that its temperature was 92° F., and the quantity discharged 50 gallons per minute. It is well known that the metalliferous region of Cornwall contains faults or "cross-courses" running from the lodes to the sea. At the Huel Clifford mine there is a well-defined cross-course which can be traced direct from the mine to the sea, and here at the depth of 1320 feet below the sea level a so-called "spring" of water containing 363·61 grains of sodium chloride to the gallon, breaks into the mine, pouring in a stream of 150 gallons per minute, or 864 tons of water daily. This water has a temperature of 125° F., the highest reading that I have found in any foreign mine.

The conditions under which this heated water breaks into the lodes seem to forbid absolutely any other supposition than that it comes direct from the ocean, and obtains its heat in its journey. I believe the most moderate computation of the age of the Cornish lodes places them only at some date later than the Devonian, and in their case there can be no supposition of remaining eruptive heat at the moderate depth of these waters. The heat is a product of the present time, and if it does not come from kaolinization, the waters at least give no sign of any other action. Mr. Phillips' analysis shows that there is only 2·12 grains of calcic sulphate, and no other compound of sulphur, in the water, and his analyses of the dyke material, granite, unaltered and altered clay slates, all show the reason for the absence of sulphur from the water. None of these rocks contain more than a trace of sulphur, and the metalliferous region of Cornwall seems to resemble the Comstock closely in this respect. Mr. Phillips' valuable paper in fact supplies the strongest direct proof we have of the chemical origin of earth temperatures.

So far as we have found, the layers of fissured rock which exist in the Comstock region play an important part in two distinct *rôles*. They are the hot belts and the reservoirs of water, and now they are found to act as the furnaces of the district also. Filled with water at a considerable pressure, they present an enormous surface to its action, and kaolinization goes on simultaneously at all points within them until they reach that stage in which they answer the description given of some clays that form seams 100 or 200 feet thick, and consist of angular fragments of propylite cemented together by more plastic material. Each one of these nuclei represents an independent centre of action ; and little as we know of the specific amount of heat given by this process, it is probable that the alteration of a propylite layer 2000 feet square and a hundred yards thick, progressing at one time in every part of its mass, would furnish a large amount of heat. Layers of this and smaller dimensions are found on both sides of the vein, and in all the rocks of the region. Sometimes widely separated, they also frequently lie within 100 or 200 feet of each other. Considering the low specific heat and conductivity of rocks, it is not surprising that a temperature of 130° Fahrenheit should have been reached and maintained by this action at depths of 1500 feet and more, where radiation is necessarily slow. A layer one hundred yards thick, containing 1,200,000,000 cubic feet, would, if the moisture amount to five per cent, combine with 4,600,000 tons of water. An allowance of three per cent of water for all the rock within 1000 feet of the lode is extremely small considering the great abundance of the clay, but even that gives 90,000,000 tons of combined water above the 2000-foot level, and for a length of 20,000 feet. Thus while the evidences of oxidation are comparatively insignificant, the solidification of water has been upon a very great scale, the largest figures given here being probably no more than a fraction of the real quantities.

While the hot belts, cold belts, and water-bearing shattered layers are the more striking features of this ground, they are of less importance in a theoretical sense than the dry rock. It has already been mentioned that the dry ground is very much in excess of the wet, forming, in fact, the great mass of the country rock, and also that it is as hot as the wet seams usually are. It has further been shown that conduction alone cannot account for the quantity of heat passing through this dry rock, and any theory which is to satisfy the heat phenomena of the Comstock must first of all explain the extraordinary flow of heat through it. Though the theory of heat from kaolinization was entirely deduced from the evidence presented by the rocks that had been acted on by water, one of its principal claims is that it affords a natural explanation of the heat in the dry rocks as a necessary consequence of the chemical change indicated.

The vehicle for the conveyance of this heat I conceive to be gaseous currents, heated by the chemical action spoken of, penetrating the rocks in every direction, and tending to discharge themselves into any free channel, like a drift, opened in the ground. The source of this gas is primarily the atmosphere. Water is capable of absorbing 0·025 of its own volume of nitrogen, 0·046 of oxygen, and its own volume of carbonic anhydride at the ordinary atmospheric pressure. At a higher pressure the absorption is greater, and as the water in the rocks 2000 feet below the surface is under a considerable hydrostatic head, it probably contains a maximum quantity of gas.

The fixation of the water in the solid form, by combination with the aluminic silicate, necessarily liberates the gas it has dissolved, and this gas must then seek to discharge itself at the only point that is free under natural conditions—the surface. On its way upward it continually meets fresh supplies of water, and is reabsorbed until the water becomes saturated. As the water would always carry down carbonic anhydride and air derived from meteoric sources, there would be additions at every rainfall to the store of gas in the strata, and the cumulative results of years of this action must be the saturation of the rocks with gas, so that whatever is liberated by the solidification of the water will find no place to rest without pushing out some of the gas already held so abundantly in the interstices of the rocks. From the point where this chemical alteration of the feldspar takes place there must be a discharge of gas at least equal in quantity to the rainfall which reaches that depth, and this stream of hot gas will take its way to the surface and maintain the heat lost by radiation from the rocks through which it passes.

Owing to the well-known fact that porous substances saturated with water are closed to gases, to which they cannot give passage, the streams of hot gas are necessarily confined to the dry portions of the rock. We have seen that most of the Comstock country rock is dry, the wet layers forming considerable but isolated masses within it. These have been called the furnaces of the region, and the dry portions are its chimneys. No difference has been noticed in the temperature of the two members, but observation has not been directed especially to this point.

Under these circumstances it is not difficult to understand the mode in which the immense quantity of heat carried off by the ventilating current is brought into the drifts. Evidences of gas currents that do not come from crevices merely, but from the solid rock, are not wanting. In passing through the mines, my attention was early called to the fact that a candle-flame will often flare when held in front of a drill-hole, and no other phenomena of the mines had aroused the curiosity of the men so strongly as this. I was frequently appealed to for an explanation of it. "Blowers" of gas are met with, but they are not remarkably strong. A number of men were nearly suffocated in the Justice lately by gas given off at the header; but such occurrences are not infrequent in other mines. The only phenomenon that has interest and importance is the flow of gas from the solid rock. That is a well-established occurrence, and affords strong proof that the action suggested is actually in progress.

In speaking of the hot spots found in the rock, it was pointed out that they are most frequent near the black dyke, and the hottest of them was in the dyke vein on the Imperial 2001 level. Such a belt of broken rock offers a ready passage for gases, and the higher heat is sufficiently accounted for by the more rapid passage of hot gas in this situation. Perhaps the deadly effects of these very hot places may be due partly to the character of the atmosphere in their immediate neighborhood. In fact, there are some contradictory features in the hygiene of these mines that are suggestive. The men work with extraordinary vigor and without injury in temperatures much higher than those which produce fatal casualties every summer in American cities; but this is true only where these temperatures are common to a large extent of rock. If the heat rises in any one part, bad effects are not uncommon. In proof may be cited the deaths in the Imperial incline and the Gould & Curry 1900 winze, both of them being excavated probably in hot belts. The highest water temperature observed (156°) was in the edge of the dyke on the Julia 1800 level. It is probable that the dyke vein having ceased to give passage to metalliferous waters is now the seat of hot gaseous currents.

It would be interesting to learn the rate at which heat passes through these rocks under the combined operation of gaseous currents and ordinary transmission. Ample opportunities exist for trustworthy experiments upon the subject, for there are scores of diamond-drill bore-holes, each some hundreds of feet in length, on different levels in all parts of the lode. But no data have been collected even for such rough calculations as I have ventured upon in this chapter.

On this account it is equally impossible to apply, at present, Joule's discovery that gases do not lose heat, or not so much heat, in expanding when they pass through a porous plug as when they are delivered freely. The rock evidently acts as such a plug to any gases contained in them. Nevertheless, the fact is, it does cool rapidly; its rate of transmission, excessive as it is when compared with Sir William Thomson's formula, not being sufficient to maintain its temperature undiminished with an air-current passing. To what depth this refrigeration extends is not known.

In the Comstock all the rocks, propylite, diorite, and andesite, show this tendency to break up under the action of water. On the surface there are areas where the alteration has been deep, and others of just as ancient exposure, where hardly anything more than discoloration has taken place, the material remaining firm. A similar state of things is found below the surface, and at all depths reached by the works. Soft seams, hard rocks, which remain hard through years of exposure, and hard rocks which flake down and soften under the action of the air, are all met with, and apparently are not distinguished by mineralogical differences. In addition to these variations, the cold belts which were pointed out as one of the most extraordinary phenomena of the lode present a condition of things which cannot be regarded as accidental, but must have some important underlying cause.

This cause is probably to be found in the varying susceptibility of the rock layers to decomposition. The Comstock rocks have been the seat of kaolinization and heat generation for an indefinite but certainly immense length of time. Some layers were probably more susceptible to alteration than others, and in them the work began and was also completed first; and perhaps we may identify some of these seats of early heat production in the plastic clays of the region. Others seem to remain hard, and, in fact, what is here called susceptibility to alteration may really be no more than progressive shattering from the slow but constant movement of the ground. A layer would have its surfaces, and consequently its liability to alteration, vastly increased by breaking up, and this dynamic action has probably been spread over the whole period subsequent to the principal elevation.

We may therefore look upon some of the wet rock as having passed its *maximum* rate of alteration, and where such layers preserved their hardness they would now be free from heat generation, and exhibit the striking contrast of the cold belts. Others, less favorably situated for the action of water at first, are now in a condition to favor alteration and heat production, and they form some of the existing hot belts. Other hot belts of dry rock are heated by gases as before said.

This contrast of hastened and delayed decomposition is also exhibited by the whole mass of rock. It is still doubtful whether terrestrial or meteoric waters have played the larger part in producing the heat of these rocks; but the importance of meteoric waters in this work is proved by the comparative coolness of the rocks throughout the first 800 feet of depth. That area covers the portion which was first presented to the action of water, and it would naturally reach its *maximum* first and now be cooling off, while in the second thousand feet of depth we find rocks undergoing delayed decomposition, and therefore at their *maximum* activity now. Whether we can go still further with the comparison and conjecture that underlying these there are rocks which are cool because they have not yet reached the point of active alteration, or are below the reach of water supply, is a question that cannot be settled.

Relation of Temperature to Depth.—The study of heat phenomena in the Comstock gains interest from the fact that mines excavated in similar material in Mexico are also hot, and further there are several mining districts in the West which repeat the conditions of the Comstock with sufficient exactness to give reason for expecting a similar state of things in them. Indeed, the explanation here given of terrestrial heat phenomena has a much wider application. It is plain that the presence of gaseous currents in the strata of the earth cannot be confined to the region of the Comstock lode, but must take place wherever meteoric waters are carried into low-lying strata, and there enter into chemical combination with mineral substances. The regenerative action by which each dose of rain-water intercepts the escaping currents of gas, as they rise through the rocks, and adds to the store it has brought from the surface, until the point of saturation is reached, must also go on wherever hydration takes place in underlying rocks. Extreme discrepancies exist in the records of subterranean rock temperatures, so far as they have been observed, and they have never been explained, but it seems probable that wherever kaolinization is taking place the temperature, both of the strata affected and of those overlying them, will be raised.

In the Comstock we find two classes of heat phenomena, the ordinary one of the great mass of rock and the extraordinary one of the hot belts. I am constrained to point out again the fact that my observations are not sufficient to be made the basis for a comparison of these interesting conditions, and the subject of the increment of heat with depth is discussed here merely for the criticism which it affords upon the results obtained in artesian wells in other localities where the actual conditions were absolutely unknown.

Mr. King gives 108° F. as the highest heat of the rock "in the lowest workings" of the Empire, Crown Point, and Hale & Norcross mines in 1869. That depth was 1000 to 1200 feet. If we assume the increase to be uniform from 108° on the 1000 to 130° on the 2000 level, as found by me, its rate will be $1000 \div 22 = 2{\cdot}2°$ F. for 100 feet or 1° F. for 45·45 feet.

Mr. King's observation is given as a *maximum*, and he gives several readings of rock temperature in the 930 level of the Hale & Norcross which vary from 72° to 84° F. ; in the Yellow Jacket 733 feet, varying from 78° to 88° F. It is probable that the *average* temperature in the lowest workings mentioned was not above 100° F., and from this figure we may obtain two readings. First, $130°—100° = 30°$ may be taken as the increment of temperature in $2000—1100=$ 900 feet of depth, and this gives a mean rate of $900 \div 30$, or 1° F. for 30 feet of depth. Second, this temperature on the 1100-foot level might be compared with that on the Jacket 2200 level (139° F.). Then we have an increment of 39° in 1100 feet of depth, or 1° F. for 28 feet of depth.* In this case the result is doubtful because a mean temperature on the 1100 level has been compared with a reading that probably indicates the position of a hot belt on the 2200.

It would be more reasonable to compare King's *maximum* reading with the similar *maximum* in my observations, and then the difference for 1100 feet depth is 139°—108°=31° F., or one degree increase for 35½ feet of depth.

Here we have three different rates of increase due to the difficulty of correctly estimating the value of variations that are perceptible in known ground. When we find elsewhere that the increment is given as 1° F. for 30, 36, 47, 51, 59, and 77 feet of descent, we are driven to the conclusion that observations upon earth temperatures cannot be considered a basis for accurate deduction until the agencies working within the rocks are properly investigated for each locality.

Of the three rates of increase obtained above, I suspect that the lowest probably approaches the true mean increment in this ground, and that the increase of temperature is not far from 1° F. for 45 feet of depth. It is to be noted that while these calculations are based upon vertical depth, the path of water and gas is always inclined. The country rock is so full of clay seams, dykes, and layers of dense propylite, all of them bedded with the formation, that the line of movement must be essentially with the dip. In this way the agencies which produce and distribute the heat have paths which are approximately one half longer than the vertical height.

Another point of interest is the vertical localization of the phenomena. The Comstock surface is strongly accidented, and though the high temperatures are found under the more elevated portion of the ground, no relation can be discerned between these situations. From the Yellow Jacket to the Justice, in a direct line, the distance is a little more than 6000 feet, the latter being about 3500 feet east and 5000 feet south of the Jacket, and it also lies 500 feet lower. The descent is therefore one foot in twelve, and the Justice 1150 level lies 1864 feet below Point A, while the Jacket 1531 is 1964 feet below the same datum. The Justice is a perfectly cool mine, no sign of high rock temperatures having been noticed in it, while the Jacket 1531 had a temperature of 123° F. in fresh ground, and there was probably a difference of at least 40° in the temperature of the two localities. I doubt if much profit could be gained by discussing the position of geothermal lines in ground where such differences are found within the distance of a mile. In looking over Mr. King's table of temperatures it will be noticed that the rock at the *mouth* of the Chollar-Potosi shaft had a temperature of 83° F.; Hale & Norcross, 930-foot level, 83°, 84°, 74° and 72° F.; Yellow Jacket, 570-foot level, 76° F., and that generally there is no uniformity in the temperatures observed on similar levels. Certainly it would be difficult to discern a progression regular or irregular. On the whole, the facts indicate the probability of the suggestion made above, that the upper portion of the lode, what we may call roughly the first thousand feet of depth, was chemically inactive, or in a condition of only very moderate heat generation, and that below it lies a zone of great chemical activity in which the production of heat has gone on increasing as the zone was penetrated. It is a matter of great consequence to the miners to know how far this increase will continue, and whether it will reach a point prohibitory to mining within the extreme depths which modern mechanical appliances permit us to reach. The subject is approached with great diffidence, for there is absolutely no basis for reasoning, and but few facts upon which to rest conjecture.

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* In the paper presented to the American Institute of Mining Engineers this result was given as one degree for 25 feet, the depth of the "lowest workings" in 1869 being taken at 1000 feet. Subsequent investigation has convinced me that this is less than their actual depth at that time, and it is now taken at 1100 feet.

The facts in question are entirely confined to the temperature of the water, which is the highest found in any material. In the mines it reached 158° F. in the Julia 1800 level, and at Steamboat Springs, twelve miles from the Comstock, there is a perennial spring supplying water a little above 212° F. It is said that these springs have failed noticeably since the mines entered upon their deep workings, and drew 10,000,000 or 15,000,000 tons of water from the lower levels. At the same time the mine water has become considerably hotter. Are we therefore to suppose that the water of Steamboat Springs is boiling hot because it rises from great depths, and that the miners are rapidly nearing a region where their work will be impossible? To this question we may positively answer *no*. The water boils in Steamboat Springs not because it is drawn from great depths, but for the contrary reason that it has a shallow source. The rocks of that locality are probably undergoing delayed decomposition, and therefore chemical action is now at its *maximum*. Further within shallow depths the ordinary effect of water upon the aluminous rock would be powerfully assisted by the presence of organic acids dissolved by the water from the soil. The condition of the rock is described by King (Vol. I., p.554), who says, "There is in the lowlands a considerable development of hornblendic propylite in which decomposition has reached an advanced stage. The staff-like growth of the hornblende is traceable in some of the better preserved crystals, the nature of the ground-mass is totally obscured, and the feldspars are altogether kaolinic." Here kaolinization has been extremely active, and the heat is at its *maximum*. Even if the same waters drain away into the mines, there is no proof that they would attain the boiling temperature in the Comstock rocks, for the effect of the organic acids should be realized completely long before they could reach that locality.

We may then confine our estimates to the Julia flood of 1879, which is reported to have had a temperature two degrees higher than that observed by me in that mine, or 158° F. Starting with a temperature of 130° F. on the 2000 level, and allowing an increase of one degree to 45½ feet, the difference of 28° would indicate that at 45½ × 28 = 1274 feet of further depth, or at the 3274 level, there may be rock of this temperature. This is based upon the crude notion that there must be rock somewhere to heat the water to this temperature, and it ignores the fact that the heat indicated may be entirely confined to the shattered stratum in which the water lies, and therefore may be no deeper than the existing works of the Julia.

The greatest depth to which engineers of the present day are looking forward as the maximum to which they may be called upon to sink is from 4000 to 6000 feet. The former depth will no doubt be reached by the present generation at many points, and within the year shafts have been commenced on the Comstock which are designed to reach to or near the greater depth.

If the heat of the general mass of rock increases at the rate of one degree for 45·5 feet, and the temperature at 2000 feet is 130° Fahrenheit, the increase for 2000 feet more would be 44°, and the temperature at the 4000-foot level would then be 174° Fahrenheit; at the 6000-foot level it would be 218°.

By the maximum rate of increase calculated above, or one degree to 28 feet, the temperature at the depth of 4000 feet would be 201½°, and at 6000 feet depth 273°.

Finally, to the question whether it is possible for the mining works to push through the zone where kaolinization is active and reach a cooler zone below, I should say that this can hardly be. Alteration probably extends to great depths, and mining on the Comstock is not likely to lose its present unenviable distinction of work accomplished under the most extraordinary conditions known.

THE END.

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